CHAPTER 5

DRAFTING: PROJECTIONS AND SKETCHING

This chapter deals with the theory of projections and methods of preparing projection drawings. By applying basic geometric construction (described in the preceding chapter) to the various projection methods, you should be able to clearly represent any given object or structure on paper. Although the methods discussed here are basic to all drawings, they are easily adapted to construction drawings. This chapter also covers various techniques of freehand sketching. You will learn how to prepare quick sketches to convey or develop your ideas.

Every object or structure you draw has length, width, and depth, regardless of its size. However, you must draw the object or structure on paper, which is a flat two-dimensional plane. To show the three dimensions by lines alone, you must use either a system of related views or a single pictorial projection. You must be able to show clearly the shape of the object, give the exact size of each part, and provide necessary information for constructing the object.

In theory, projection is done by extending lines of sight (called projection lines) from the eye of the observer, through lines and points of an object being viewed, to the plane of projection.

PARALLEL PROJECTION

To satisfy requirements for preparing single- or multi-view drawings, you may use two main types of projection: PARALLEL and PERSPECTIVE (fig. 5-1). PARALLEL projection

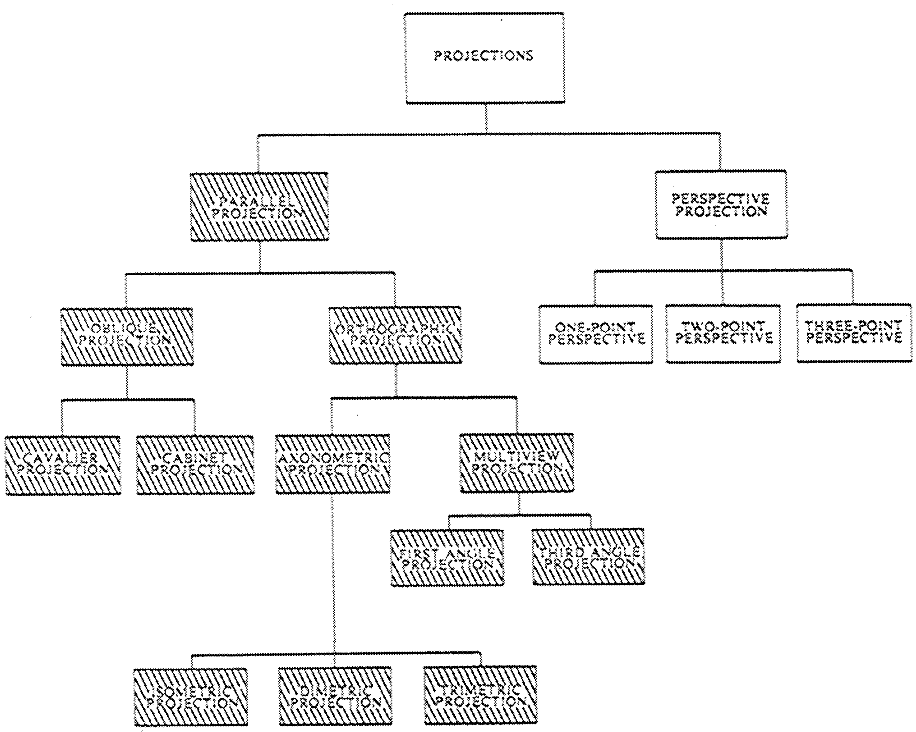


Figure 5-1.—Classification of major projections.

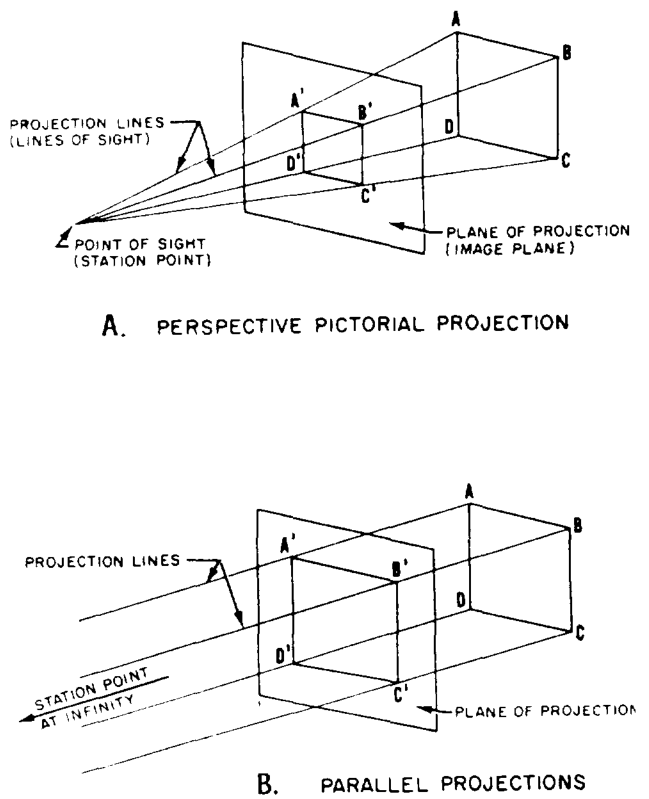


Figure 5-2.-Types of projections.

(fig. 5-2) is further classified into subtypes according to the direction of its projection lines relative to the plane of projection. If the projection lines, in addition to being parallel to each other, are perpendicular (normal) to the plane of projection, the result is an **orthographic** projection. If they are parallel to each other but oblique to the plane of projection, the result is an **oblique** projection.

To better understand the theory of projection, you must become familiar with certain elements that are common to each type of projection. Some of these elements are defined below.

The POINT OF SIGHT (or STATION POINT) is the position of the observer in relation to the object and the plane of projection (fig. 5-2). It is from this point that the view of the object is taken. The point of sight is changed to give different views of the same object; hence, there must be a different point of sight for each view. Imagine yourself looking first at the front of an object, then down at the top, and then at the right or left side, as the case may be. Each additional view requires a new point of sight.

The observer views the features of the object through an imaginary PLANE OF PROJECTION (or IMAGE PLANE). In parallel projection, this theoretical transparent plane is placed between the point of sight and the object, as shown in figure 5-2. For perspective pictorials, it

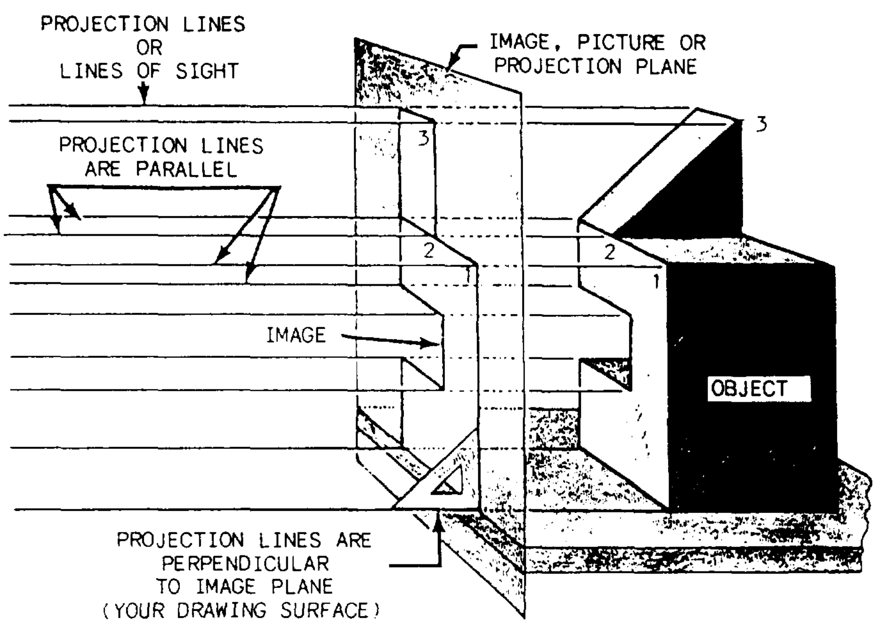


Figure 5-3.-Basic orthographic projection.

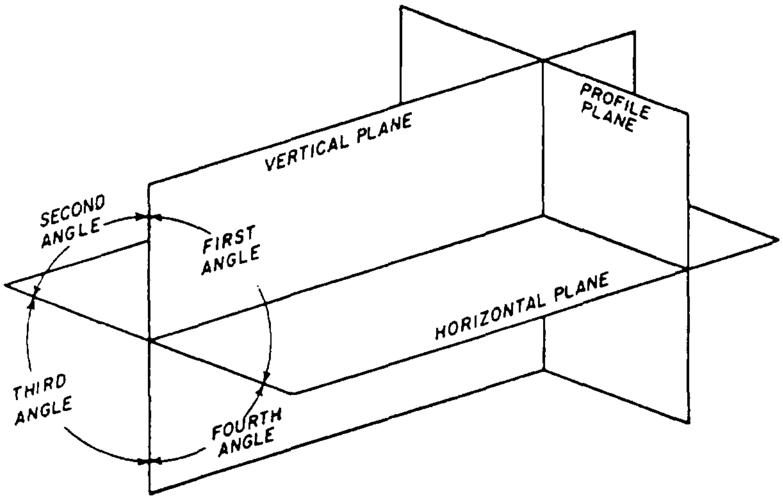


Figure 5-4.-Primary (principal) planes of projections.

is normally placed between the point of sight and the object. For the purpose of studying any type of projection, it must be assumed that the planes of projection are in fixed positions. Once the object is placed in a definite imagined position, it should never be changed. If a different view of the object is desired, the location of the point of sight is changed.

The PROJECTION LINES (or LINES OF SIGHT) are the imaginary lines from the eye of the viewer (point of sight) to points on the object (fig. 5-2). By the use of projection lines, points on the object are projected on the image plane. These points are the points at which the projection lines appear to pierce the image plane. By the projection of the prominent points, lines, and surfaces of an object, a complete view of that object can be projected on the plane of projection.

The relationship between the point of sight (station point), the plane of projection (image plane), the projection lines (lines of sight), and the manner in which they are used for each individual type of projection will be discussed in the following sections.

ORTHOGRAPHIC PROJECTION

When you are called upon to draw a three-dimensional object or figure, it is customary to represent the parts and forms on the flat plane of the drafting paper in such a manner that all features are shown in their true dimensions and in their true relationship with other features on that part of the object. To do this, you must draw a number of views of the object from different angles. Projecting these essential views into a single plane is known as ORTHOGRAPHIC PROJECTION. The term *orthographic is* derived from the word *orthos* meaning perpendicular or right-angular.

Multi-view Projection

When an object is viewed through a plane of projection from a point at infinity, an accurate outline of the visible face of the object is obtained (fig. 5-3). However, the projection of one face usually will not provide an overall description of the object; other planes of projection must be used. Establishing an object's true height, width, and depth requires front, top, and side views, which are called the PRINCIPAL PLANES OF PROJECTION. Figure 5-4 shows the three principal (or primary) planes of projection, known as the VERTICAL, HORIZONTAL, and PROFILE PLANES. The angles formed between the horizontal and the vertical planes are called the FIRST, SECOND, THIRD, and FOURTH ANGLES, as indicated in the figure. Currently, however, for technical reasons, only the use of first- and third-angle projection is practical.

FIRST-ANGLE PROJECTION.— A fine example of first-angle projection using a cube is

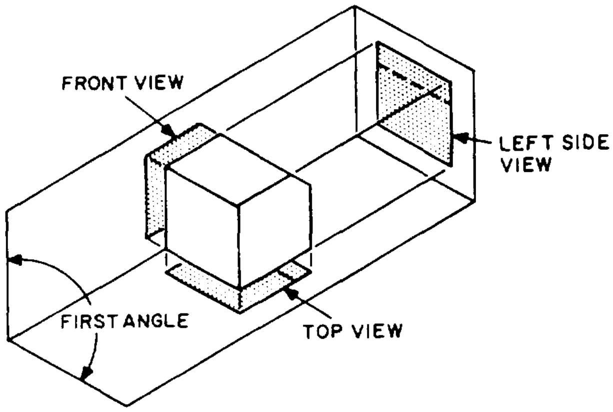


Figure 5-5.-Elample of a first-angle projection.

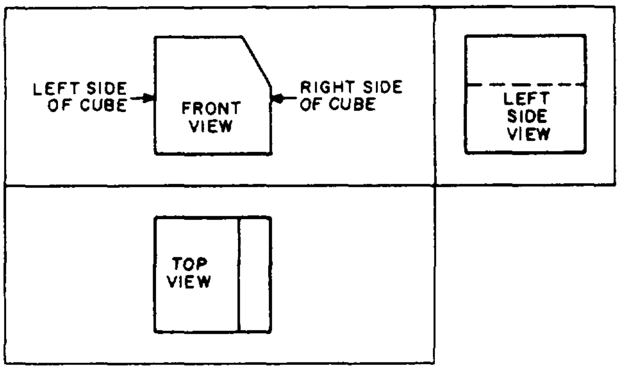


Figure 5-6.-Firsl-angle projection brought into a single plane.

shown in figure 5-5. The cube is supposed to be fronting toward the vertical plane of projection. As you can see, you get a front view on the vertical plane, a left side view on the profile plane, and a top view on the horizontal plane.

Now, to put these views on a sheet of drafting paper, you must get them all into the same plane. You presume that the vertical plane of projection is already in the plane of the paper. To get the other two views into the same plane, you rotate the profile plane counterclockwise and the horizontal plane clockwise. The projection now appears as shown in figure 5-6.

This first-angle projection arrangement of views is considered satisfactory in most European drafting practice. In the United States, it is considered illogical because the top view is below the front view; because the right side of the object, as shown in the front view, is toward the left side view of the object; and because the bottom of the object, as shown in the front view, is toward the top view of the object. For these and other reasons, first-angle projection is not used much in the United States.

THIRD-ANGLE PROJECTION.— Figure 5-7 shows a third-angle projection of a cube. As you can see, you get a front view on the vertical plane, a top view on the horizontal plane, and a right side view on the profile plane.

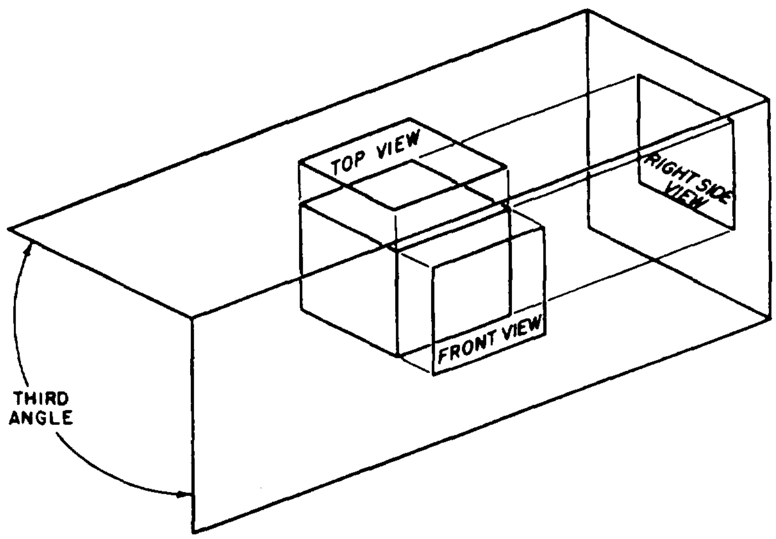


Figure 5-7.-Example of a third-angle projection.

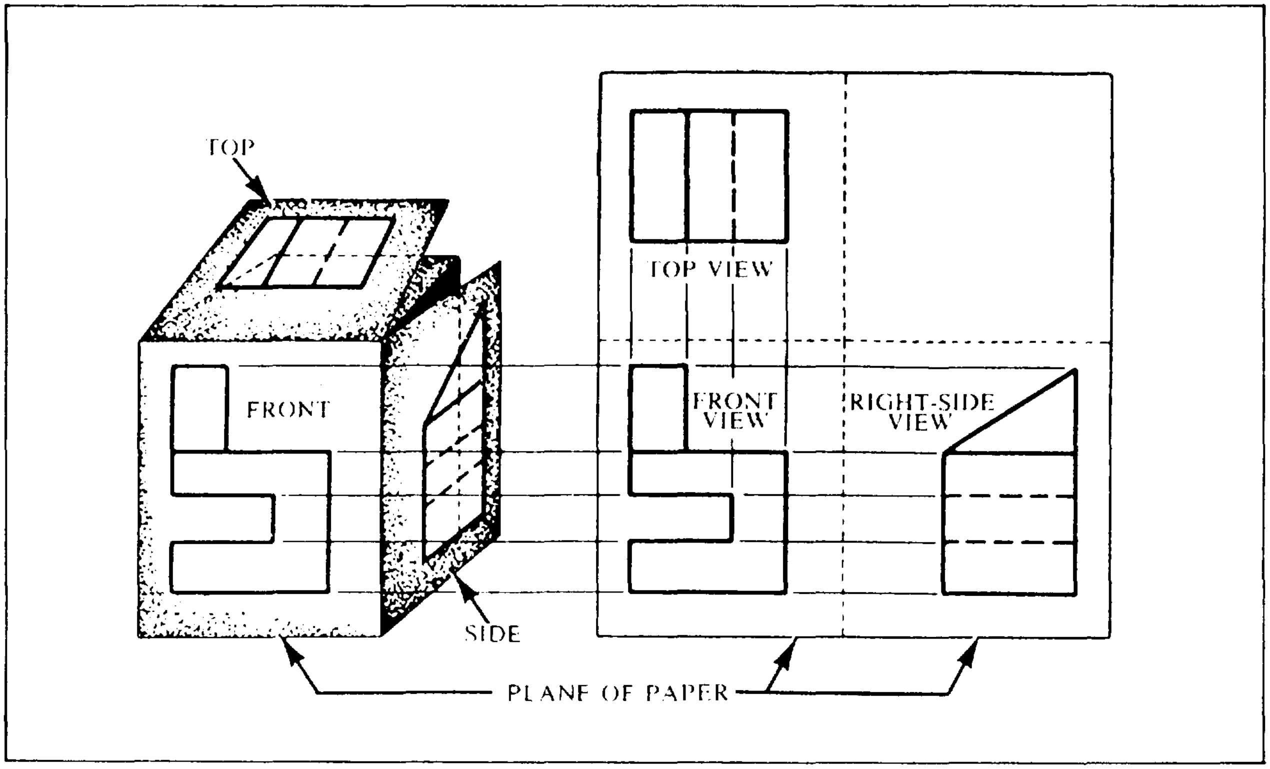


Figure 5-8.-A third-angle projection brought into a single plane.

Again you assume that the vertical plane is already in the plane of your drawing paper. To get the other two views into the same plane, you rotate them both clockwise.

Figure 5-8 shows a third-angle projection of an object brought into a single plane. The top view is above the front view; the right side of the object, as shown in the front view, is toward the right side view; and the top, as shown in the front view, is toward the top view.

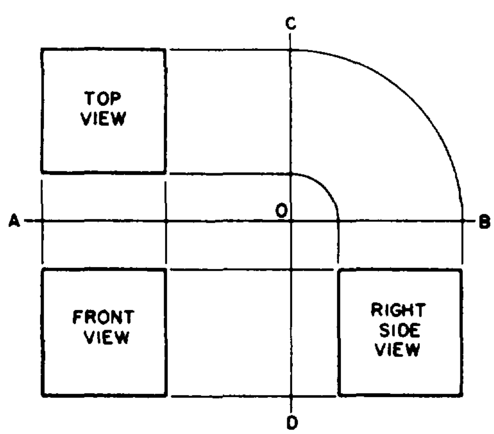


Figure 5-9.-Method of making a third-angle projection.

Figure 5-9 shows the basic principles of the method by which you would actually make the projection shown in figure 5-8. Draw a horizontal line AB and a vertical line CD, intersecting at O. AB represents the joint between the horizontal and the vertical plane; CD represents the joint between these two and the profile plane. Any one of the three views could be drawn first, and the other two projected from it. Assume that the front view is drawn first on the basis of given dimensions of the front face. Draw the front view, and project it upward with vertical projection lines to draw the top view. Project the top view to CD with horizontal projection lines. With O as a center, use a compass to extend these projection lines to AB. Draw the right side view by extending the projection lines from AB vertically downward and by projecting the right side of the front view horizontally to the right.

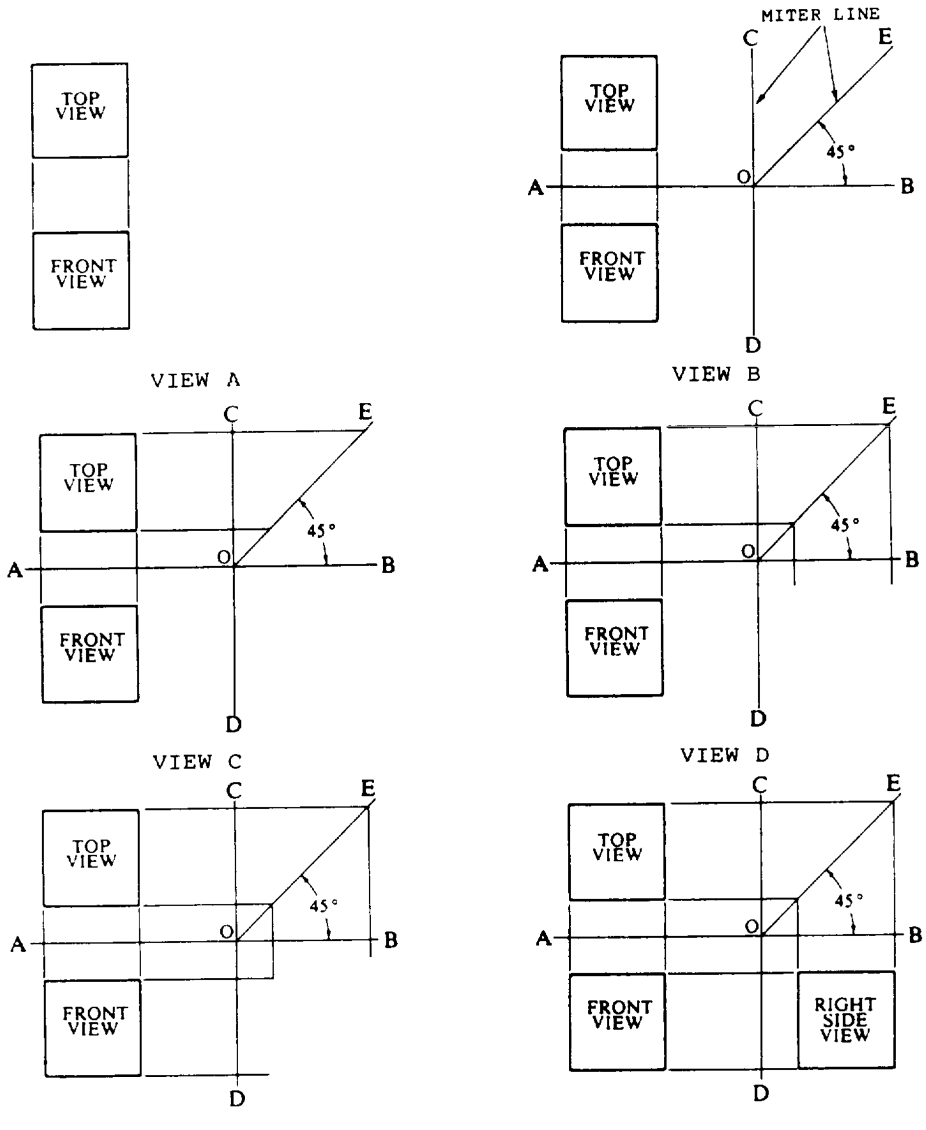


Figure 5-10.-Use of a miter line.

USE OF A MITER LINE.— A miter line (fig. 5-10) offers a convenient method of laying out a third view while you are in the process of drawing two views. Place the miter line (fig. 5-10, view B) to the right of the top view at a convenient distance, keeping the appearance of a balanced drawing. Draw light projection lines from the top view to the miter line (fig. 5-10, view C), then vertically downward (fig. 5-10, view D). Using the front view, draw horizontal projection lines (fig. 5-10, view E) to the right, intersecting the vertical projection lines. The result of this procedure is the outline and placement of the right side view (fig. 5-10, view F).

Some EAs prefer to extend the top view projection lines to the right side view using the alternate method shown in figure 5-11.

ARRANGEMENT OF VIEWS.— The six principal views of an object drawn in a third-angle projection are arranged according to the American standard arrangement of views. This arrangement (practiced since the late 1800s) depicts the relative position of the six principal views and their relationship to each other on a drafting plane.

As shown in figure 5-12, all views (except the front view) are rotated toward the observer as though they are hinged. REMEMBER, the front

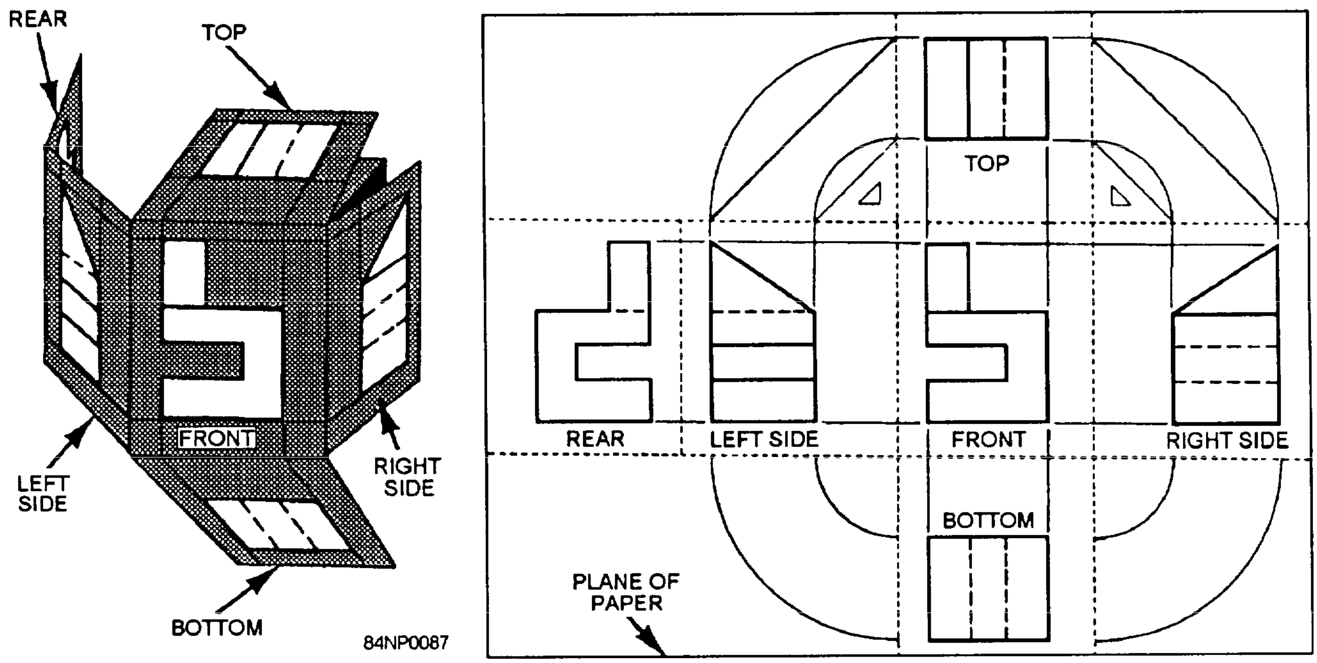


Figure 5-12.-American standard arrangement of views in a six-view third-angle multi-view projection.

view always lies in the plane of the drafting surface and does not require any rotation. Notice that the front, right side, left side, and rear views lineup in direct horizontal projection.

Use the minimum number of views necessary to show an item. The three principal views are the top, front, and right-side. The TOP VIEW (also called a PLAN in architectural drawings) is projected to and drawn on an image plane above the front view of the object. The FRONT VIEW (ELEVATION) should show the most characteristic shape of the object or its most natural appearance when observed in its permanent or fixed position. The RIGHT-SIDE VIEW (ELEVATION) is located at a right angle to the front and top views, making all the views mutually perpendicular.

SPACING OF VIEWS.— Views should be spaced on the paper in such a manner as

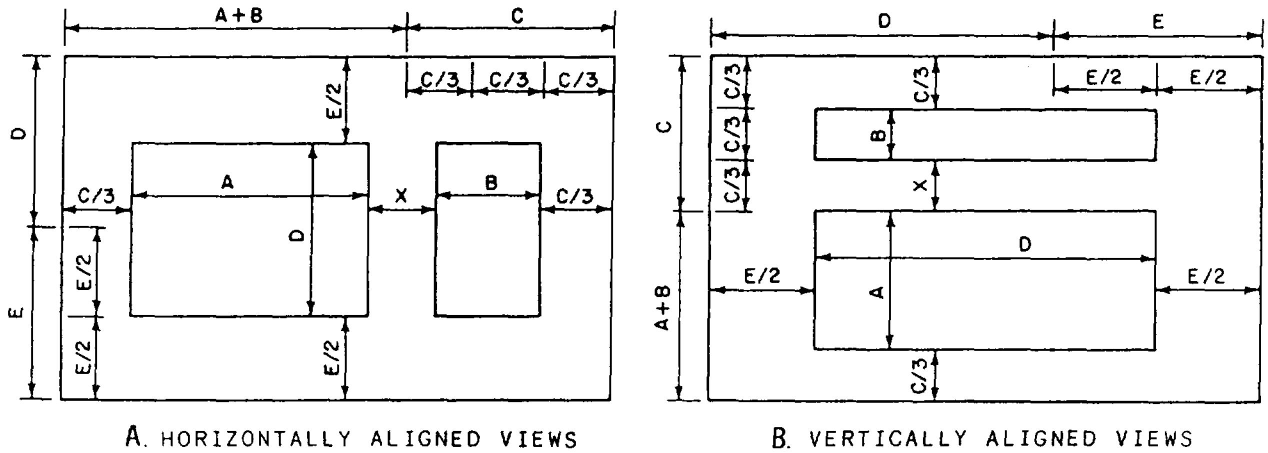


Figure 5-13.-Proper spacing of views.

give the appearance of a balanced drawing. An easy way to locate horizontally aligned views on a standard size drawing sheet is shown in figure 5-13, view A. With a compass or scale, lay off the length plus the width of the object (A + B) from one end of the horizontal margin. Divide the remaining distance, C, into three equal parts (C/3). This will be the approximate distance from either view to the vertical margin. The two views should be equidistant from the vertical margin. The spacing between views should be adjusted so that the apparent area is close to the apparent area between either view and the vertical margin. Basically, the shape of the object will determine the space between views. Generally, the distance from the views to the vertical margins and the distance between views (X) will be approximately equal. To locate the views vertically on the paper, lay off the depth of the object (D) on the vertical margin. Divide the remaining distance (E) into two equal parts (E/2). This will be the approximate distance from the top or bottom of the view to the horizontal margins.

The same method also applies to vertically aligned views on a standard size drawing sheet, as shown in figure 5-13, view B.

Proper spacing of a three-view drawing is shown in figure 5-14. As you can see, the principle is the same as that applied in spacing a two-view drawing. Distances are again equal as indicated, with distance B equal to, or slightly less than, distance A, and distance D equal to, or slightly less than, distance C.

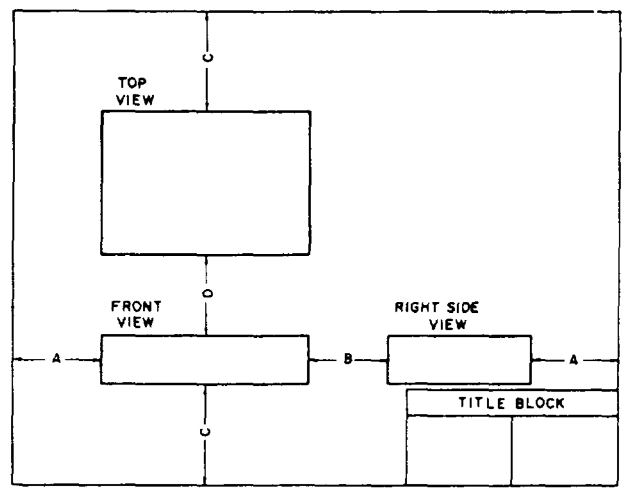


Figure 5-14.-Proper spacing of views on a three-view projection.

While the spacing of views in figure 5-14 is technically correct, the drawing has an unbalanced appearance because of the large area of empty space in the upper right corner and because the right side view crowds the title block. If the drawing will contain a sizeable bill of materials in the upper right corner, this spacing will be satisfactory. If not, it should be improved, if possible.

If the object is one that allows an arbitrary choice with regard to the designation of surfaces as top, front, and so on, the spacing can be improved by changing the designation shown in figure 5-14 and projecting the object as shown in figure 5-15. That which appears as the top in

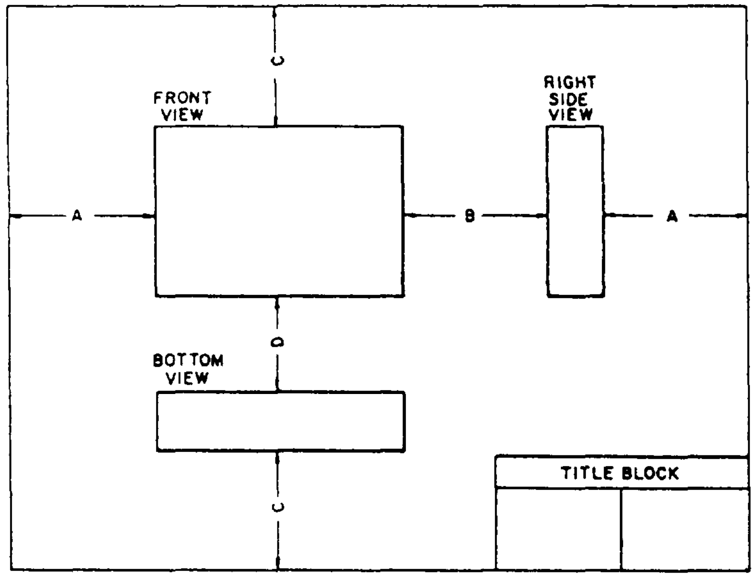


Figure 5-15.-Improved spacing for three-view projection of object shown in figure 5-18.

figure 5-14, you can now call the front; it follows that which appears as the front in figure 5-14 appears as the bottom in figure 5-15. Again the right side view appears, but it now appears in the upper, rather than the lower, right corner and vertically rather than horizontally.

Spacing views in a drawing of a circular object is like spacing letters; you try to equalize the areas of the spaces around and between the views. Figure 5-16 shows properly spaced two-view drawings of a perforated disk. For the views that are horizontally in line, you locate the horizontal center line midway between the horizontal margins; for the views that are vertically in line, you locate it midway between the vertical margins. The other spacing is as indicated. To determine the lengths of distances A and 2/3 A, set a compass to the diameter plus the thickness of the disk, and lay off this distance on the margin. Then divide the remaining segment of the margin into three intervals, two of them being equal, and the third one being 1 1/2 times as long as each of the others.

VIEW ANALYSIS.— You must be able to analyze a multi-view projection or, in other words, to determine what each line in a particular view represents. In this connection, it is helpful to remember that in a third-angle projection, the plane of projection is always presumed to be between the object and the observer, regardless

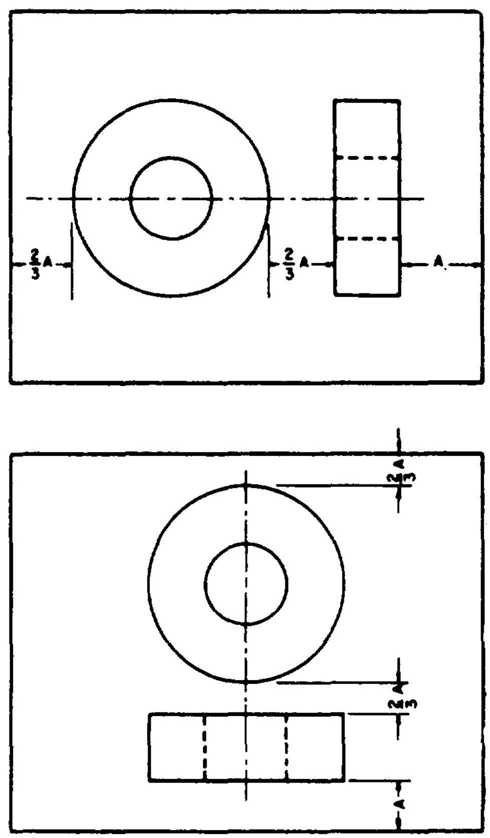


Figure 5-16.-Spacing of views of a circular object,

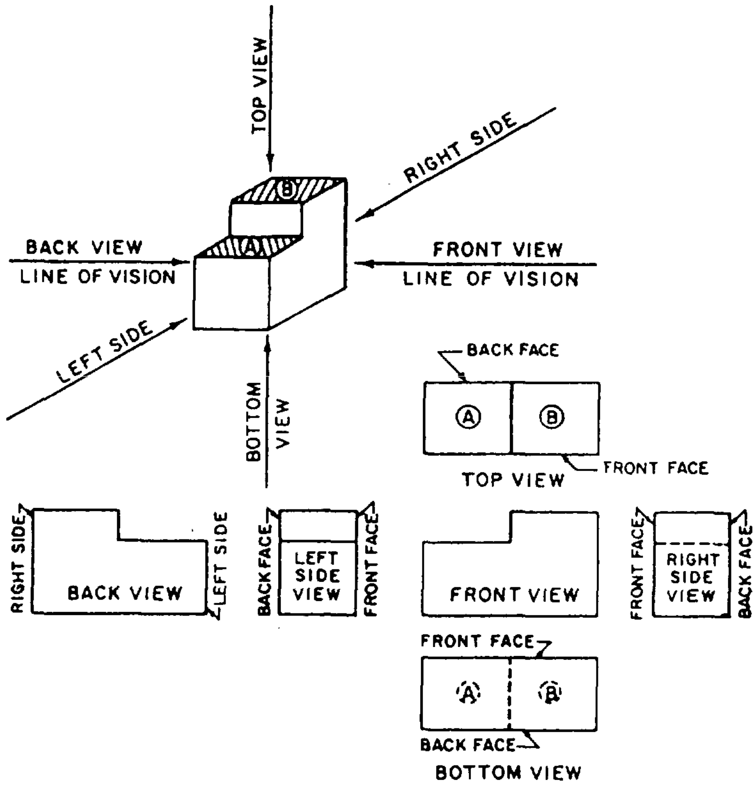


Figure 5-17.-Multi-view analysis of a third-angle orthographic projection.

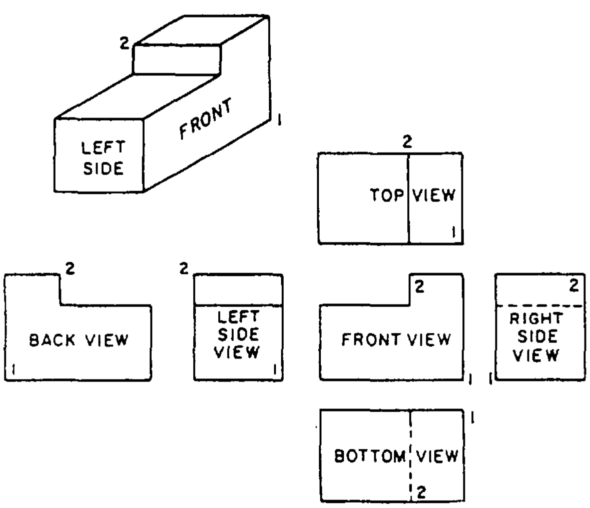


Figure 5-18.-Procedure for numbering hidden and visible corner points.

of which view you are considering. This means that, in a third-angle projection, each view of a surface of an object is a view of that surface as it would appear to an observer looking directly at it.

Figure 5-17 shows a six-view multi-view third-angle projection of the block shown in a single-view projection in the upper left corner of the figure. You should not have any trouble analyzing the front view; you know that the top is up, the bottom is down, the left side is to the left, and the right side is to the right.

In the top and bottom views, it's easy to see that the right-hand vertical line represents the right side and the left-hand vertical line, the left side. But you might have to think a minute to realize that the upper horizontal line in the top view represents the back face of the block, while the upper horizontal line in the bottom view represents the front face of the block. Note, also, that there is a line that appears as a visible line in the top view and as a hidden line in the bottom view.

In the right side and left side views, you can readily see that the upper horizontal line represents the top of the block and the lower horizontal line, the bottom. But you may have to think a minute to realize that the left-hand vertical line in the right side view represents the front face of the block, while the left-hand vertical line in the left side view represents the back face. Again, there is a line that appears as a visible line in the right side view and as a hidden line in the left side view.

In the back view, the block is shown reversed, so that the cutaway part, which appears to the right in the front view, appears to the left in the back view. Similarly, the right-hand vertical line in the front view represents the right side of the block, while the right-hand vertical line in the back view represents the left side.

As a general observation, it is helpful in view analysis to note that in the top, bottom, and side views, the line that represents the front face of the block faces toward the front view of the block. Similarly, in the back view, the line that represents the left side faces toward the left side view of the block. This applies to third-angle projection only.

A point that constitutes a corner on an object is sometimes numbered for purposes of identification in various views of the object. In a particular view of an object, a corner point number may be visible, or it may be hidden, as shown in figure 5-18. In the upper left corner of the figure, there is an oblique projection of a block, with a corner numbered 2. You can see that this corner is visible in top, back, and left side views, but hidden in bottom, front, and right side views.

The rule for numbering is that for a hidden corner point, the number is placed within the outline, and for a visible corner point, outside the outline. You can see how the rule has been followed in figure 5-18.

A multi-view projection should contain only as many views as are required to describe the object fully. If you refer back to figure 5-17, you can see at once that the back view does not convey any information that is not available in the front view; the back view is therefore superfluous and should be omitted. The same applies to the bottom view, which conveys no information not available in the top view. Likewise, the left side view conveys no information not available in the right side view.

You have the choice of omitting either the top or bottom view and either the right side or left side view. One general rule in this instance is that a top view is preferable to a bottom view and a right side view, to a left side view; another rule is that a view with a visible line is preferable to a view with the same line shown as a hidden line. Both rules apply here to eliminate the bottom and the left side views. All you need here is a three-view projection showing the top, front, and right side views.

It is often the case that a two-view projection is all that is required. The view at the top of figure 5-19 shows a single-view projection of an object. It is obvious that a top view of this object tells you everything you need to know except the thickness; a right side view tells you everything you need to know except the length; and a front view tells you everything you need to know except the width. All you need to do, then, is to select a particular view and couple it with another view that gives you the dimension that is missing in the first view.

There are three possible two-dimensional projections of the object shown in A, B, and C. In the selection of one of these three, everything else being equal, the balance of the drawing would be the deciding factor. Either A or B appears better balanced than C, and between A and B, A would look better on a long oblong sheet of paper, and B, better on a shorter oblong sheet.

The object shown in figure 5-19 has a definitely designated top and front; it follows that the right and left sides are also definitely designated. This is the case with many objects; you have no choice, for example, with regard to the top, bottom, front, and back of a house.

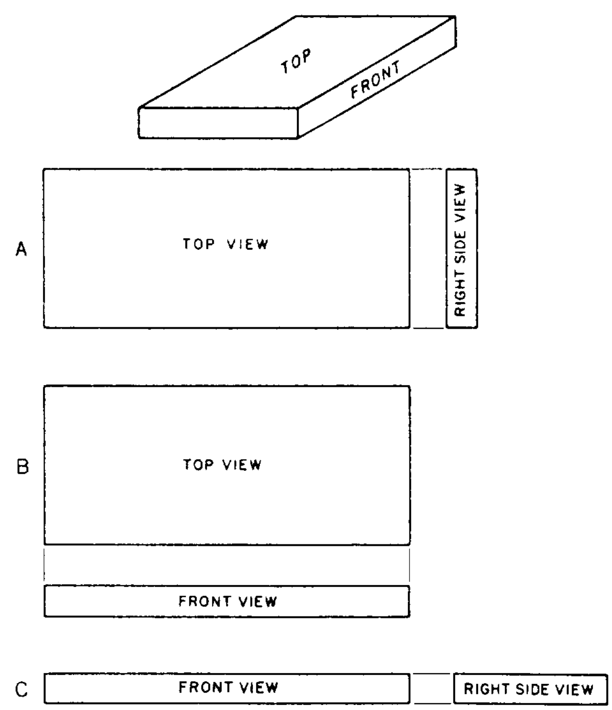


Figure 5-19.-Two-view multi-view projections.

Many objects, however, have no definite top, bottom, front, or back—as many types of machine parts, for example. With an object of this kind, you can select a surface and call it the front, and select another and call it the top, according to convenience. However, it is a general rule that an object should be shown in the position it customarily occupies.

One-view drawings are permissible for objects for which one view and such features as thickness or length, stated as a dimension or note, can completely define the object.

NORMAL AND NON-NORMAL LINES.— In a multi-view orthographic projection, a NORMAL line is one that is parallel to two of the planes of projection and perpendicular to the third. A line that is parallel to a plane of projection will appear on that plane in its true length (to the scale of the drawing). A line that is perpendicular to a plane of projection will appear on that plane as a point.

A line that is perpendicular to one plane of projection must of necessity be parallel to the other two. But a line that is parallel to one plane of projection may be oblique (neither parallel nor perpendicular) to one or both of the others. A line that is oblique to one or more of the planes of projection is called a NON-NORMAL LINE.

If a non-normal line is parallel to a plane of projection, it will appear on that plane in its true length. However, it will appear foreshortened in a view on a plane to which it is oblique. A non-normal line may, of course, be oblique to all three planes of projection, in which case it will appear foreshortened in all regular views of the object. A REGULAR VIEW is a view on one of the three regular planes of projection (horizontal, vertical, or profile). Views on planes other than the regular planes are called AUXILIARY VIEWS. Auxiliary views will be discussed later in this chapter.

A single-view projection of a block is shown in the upper left corner of figure 5-20. This block is presumed to be placed for multi-view projection with the front parallel to the vertical plane, the bottom parallel to the horizontal plane, and the right side parallel to the profile plane. The line AB, then, is parallel to the vertical plane, but oblique to both the horizontal and the profile planes.

In the multi-view projections, you can see that it is only in the views on the vertical plane (the front and back views) that the line AB appears in its true length. In the views on the horizontal

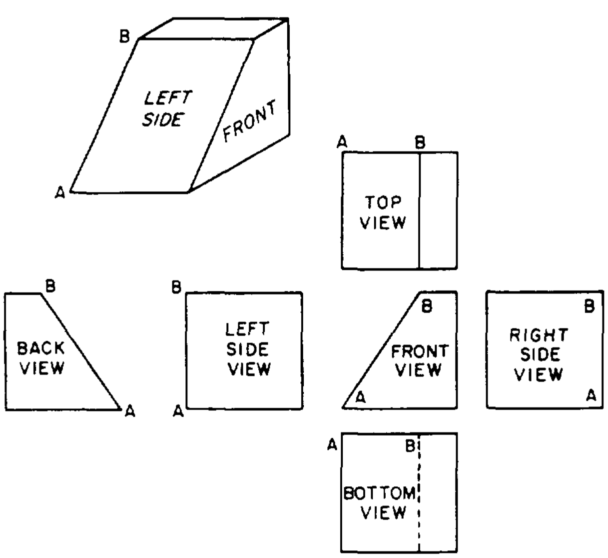


Figure 5-20.-Foreshortening of a line in a multi-view projection.

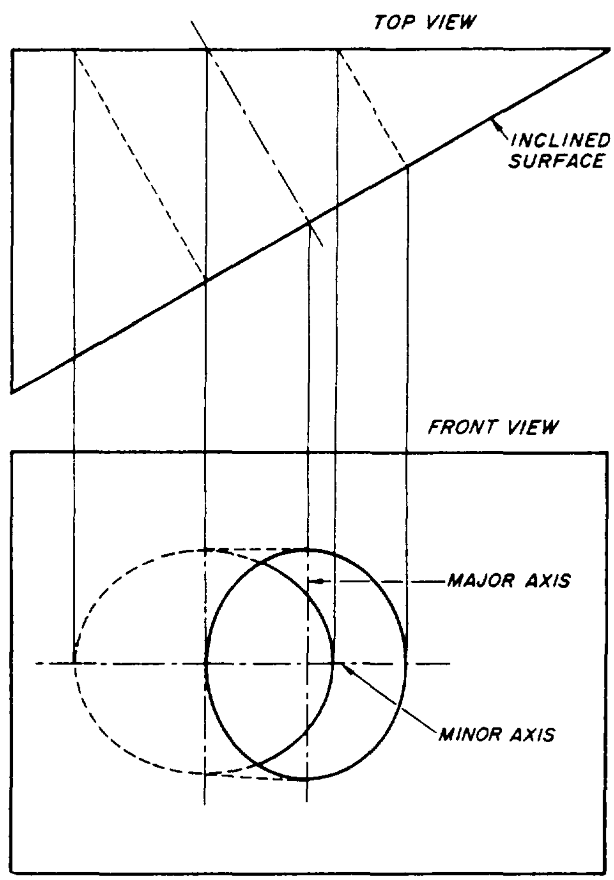


Figure 5-21.-A circle on a surface oblique to the plane of projection projected as an ellipse.

plane (top and bottom views) and in the views on the profile plane (right and left side views), the line appears foreshortened. Note, however, that you don't need to calculate the amount of the foreshortening, since it works itself out as you project the various views.

CIRCLES IN MULTI-VIEW ORTHOGRAPHIC PROJECTION.— A circle on a surface that is parallel to the plane of projection will project as a circle. A circle on a surface that is oblique to the plane of projection, however, will project as an ellipse, as shown in figure 5-21. The upper view in this figure is a top view of a wedge, the wedge having a hole bored through it perpendicular to the inclined face. The outline of this hole on the front face of the wedge projects as an ellipse in the front view. You get the minor axis of the ellipse by projecting downward as shown. The length of the major axis is equal to the diameter of the hole.

Another ellipse is shown in the front view. This is the partly hidden and partly visible outline of the hole as it emerges through the back of the wedge. The back of the wedge is parallel to the front view plane of projection; therefore, this ellipse is the true outline of the hole on the back of the wedge. The outline is elliptical because the hole, though it is circular, is bored obliquely to the back face of the wedge.

To draw these ellipses, you could use any of the methods of drawing an accurate ellipse explained in the previous chapter on geometric construction, or you could use an ellipse template.

AUXILIARY VIEWS.— In theory, there are only three regular planes of projection: the vertical, the horizonal, and the profile. Actually, it is presumed that each of these is, as it were, double; there is, for example, one vertical plane for a front view and another for a back view.

We assume, then, a total of six regular planes of projection. A projection on any one of the six is a regular view. A projection NOT on one of the regular six is an AUXILIARY VIEW.

The basic rule of dimensioning requires that a line be dimensioned only in the view in which its true length is projected and that a plane with its details be dimensioned only in the view in which its true shape is represented. To satisfy this rule, we have to create an imaginary plane that is parallel with the line or surface we want to project in its true shape. A plane of this kind that is not one of the regular planes is called an AUXILIARY PLANE.

In the upper left of figure 5-22, there is a single-view projection of a triangular block, the base of which is a rectangle. This block is presumed to be placed for multi-view projection

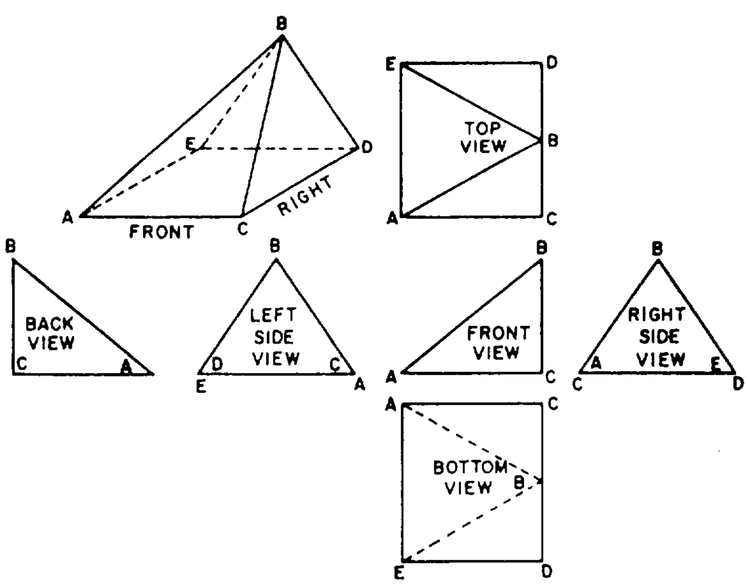


Figure 5-22.-A line oblique to all planes of projection is foreshortened in all views.

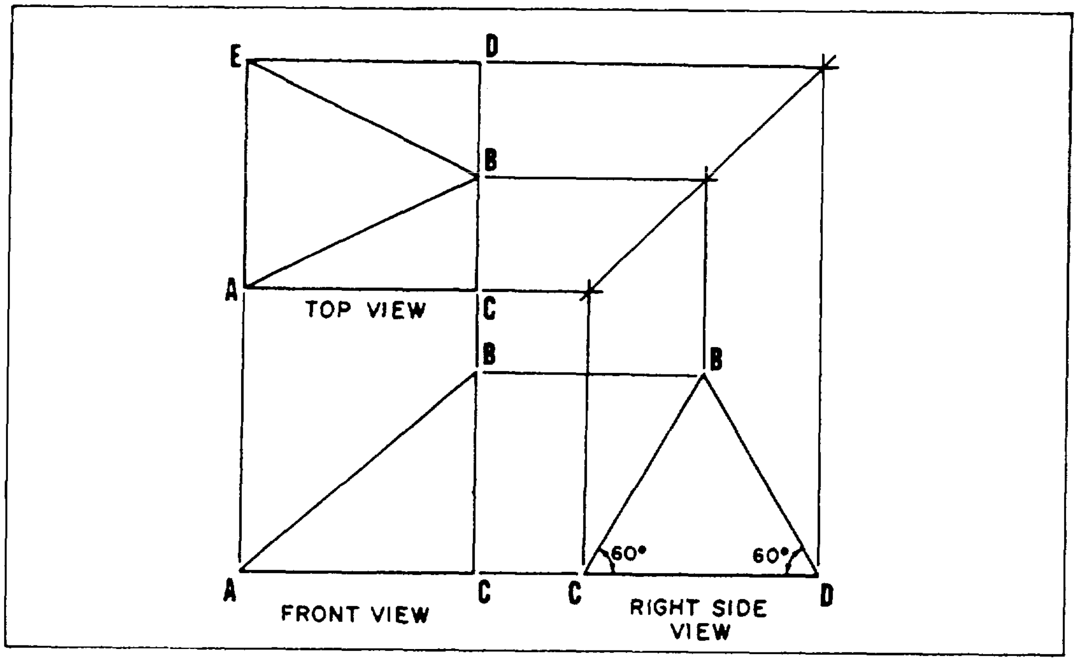


Figure 5-23.-Normal multi-view projection.

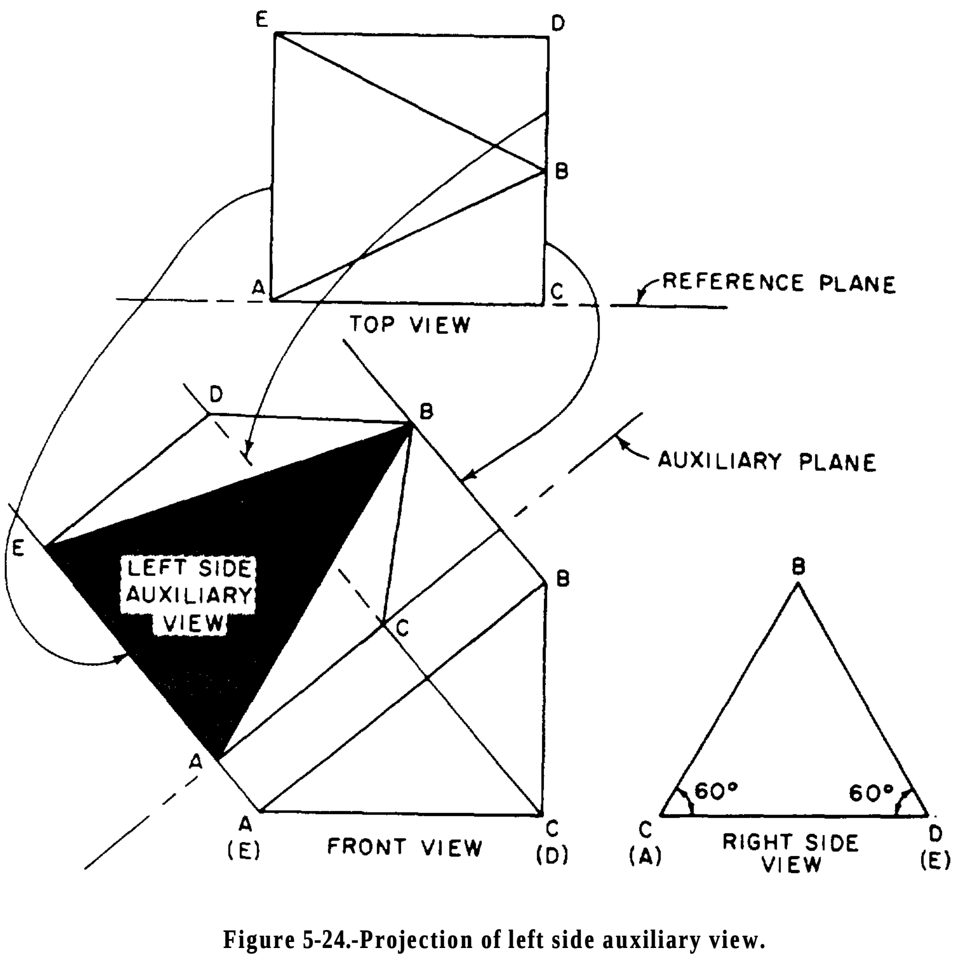


Figure 5-24.-Projection of left side auxiliary view.

with the right side parallel to the profile plane. The block is then drawn, using all six views of multi-view projection.

By careful examination of figure 5-22, you will see that the lines AB, AE, BD and BC and the surfaces ABC, ABE, and BDE are oblique to three regular planes of projection. The lines are foreshortened and the surfaces are not shown in their true shape in any of the six normal views.

The first step in the drawing of any auxiliary view is to draw the object in normal multi-view projection, as shown in figure 5-23. A minimum of two orthographic views is necessary. The space between these views is generally greater than normal. The reason for this will become apparent. Notice in figure 5-23, in the front view, that A is the end point of line AE (top view) and C is the end point of CD.

The second step is to decide which line or surface is to be shown in an auxiliary view and which orthographic view it will be projected from. The following facts must be considered when rendering this decision:

1. Front or rear auxiliary views are always projected from a side view.
2. Right or left auxiliary views are always projected from a front view.
3. An elevation auxiliary view is always projected from the top view.

The third step is to select the auxiliary and reference planes. The auxiliary plane is simply a plane parallel to the desired line or lines representing an edge view of the desired surface. In figure 5-24, the true length of line AB and the true shape of surface ABE are desired. A left side auxiliary view is needed. The auxiliary plane is drawn parallel to line AB in the front view. Line AB actually represents an edge view of surface ABE. The reference plane (top view) represents an edge view of the orthographic view (front view) from which the auxiliary view will be projected. Therefore, when front, rear, or side auxiliary views are desired, the reference plane will always be in the top view. When elevation auxiliary views are drawn, the reference plane may be in any view in which the top view is represented by a straight line. The reference plane in figure 5-24 is the edge of the top view that represents the front view. Remember that, although these planes are represented by lines, they are actually planes running perpendicular to the views.

Step four is to project and locate the points describing the desired line or surface. Draw the projection lines from the orthographic view perpendicular to the auxiliary plane. Then take the distances from the reference plane, whether by scaling or with a compass. The distances are the perpendicular distances from the reference plane to the desired point. In figure 5-24, the projection lines are drawn from points A, B, and C in the front view, perpendicular to the auxiliary plane. The projection line from point A indicates the line on which point E will also be located. The projection line from point C designates the line of both C and D, and that from B locates B only. To transfer the appropriate distances, first, look for any points lying on the reference plane. These points will also lie on the auxiliary plane where their projection lines intersect it (points A and C). To locate points B, D, and E, measure the perpendicular distances they are from the reference plane in the top view and transfer these distances along their respective projection lines in the auxiliary view. The points are equidistant from both the reference and auxiliary planes. Therefore, any line parallel to the reference plane is also parallel to the auxiliary plane and equidistant from it.

The fifth step is to connect these points. When the total auxiliary view is drawn, it is sometimes hard to discern which lines should be indicated as hidden lines. A rule to remember is as follows:

Those points and lines lying furthest away from the auxiliary plane in the orthographic view being projected from are always beneath any point or line that is closer. In figure 5-24, point C (representing line CD) in the front view is further from the auxiliary plane than any line or surface it will cross in the auxiliary view. Therefore, it will appear as a hidden line.

The final step is to label and dimension the auxiliary view. The labeling must include an adequate description. The term AUXILIARY must be included along with the location of the view in relation to the normal orthographic views (LEFT SIDE AUXILIARY VIEW, REAR ELEVATION AUXILIARY VIEW, and so forth). Dimensions are given only to those lines appearing in their true length. In figure 5-24, only lines AB, AE, and BE on the auxiliary view should be dimensioned.

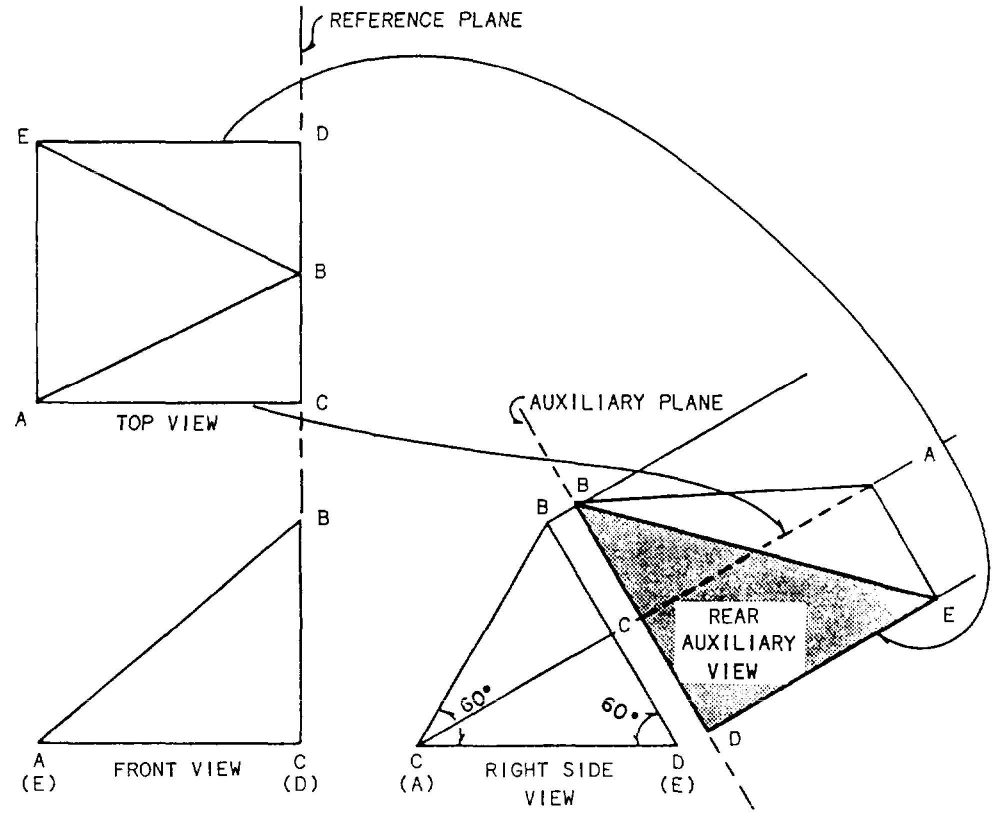


Figure 5-25.-Projection of rear auxiliary view.

Using the procedures previously described, follow the steps taken to project and draw the rear auxiliary view in figure 5-25.

Sometimes the total auxiliary view is not needed. Such a view could possibly even make the drawing confusing. In this case, a PARTIAL AUXILIARY VIEW is used. Only the points or lines needed to project the line or surface desired are used. This reduces the number of projection lines and greatly enhances the clarity of the view. If a partial auxiliary view is used, then it must be labeled PARTIAL to avoid confusion. In figure 5-24, if only the true length of line AB is desired, the points A and B would be projected and connected. The view would be complete after it was labeled and dimensioned.

In some cases the shape of an object will be such that neither the normal orthographic view nor the auxiliary views will show the true size and shape of a surface. When this occurs, a SECONDARY AUXILIARY VIEW is needed to describe the surface. The procedures for projecting and drawing a secondary auxiliary view are the same as those for a normal (or primary) auxiliary view. The reference plane for a secondary auxiliary view is located in the orthographic view from which the primary auxiliary view is projected. Usually, the primary auxiliary plane becomes the secondary reference plane. The secondary auxiliary plane is in the primary auxiliary view, and its location is determined in the same manner that the primary auxiliary plane is determined.

AUXILIARY SECTION.— An auxiliary view maybe a sectional, rather than a surface, view. In the upper left part of figure 5-26, there is a single-view projection of a block. It is desired to show the right side of the block as it would appear if the block were cut away on the plane indicated by the dotted line, the angle of observation to be perpendicular to this plane. The desired view of the right side is shown in the auxiliary section, which is projected from a front view as shown. Because the auxiliary plane of projection is parallel to the cutaway surfaces, these surfaces appear in true dimensions in the auxiliary section.

A regular multi-view of an orthographic drawing is one that is projected on one of the

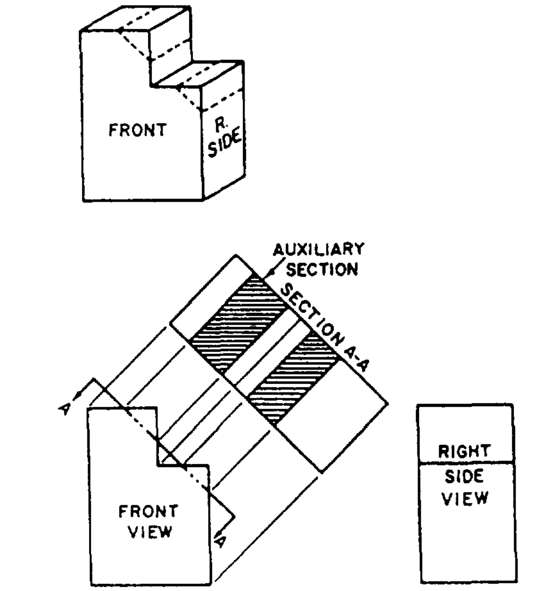


Figure 5-26.-Use of an auxiliary section.

regular planes of projection. An auxiliary view is one that is projected on a plane other than one of the regular planes.

A rectangular object is in normal position for regular multi-view orthographic projection when each of its faces is parallel to one regular plane of projection and perpendicular to the other two. This is the case with the object shown in figure 5-27, view A.

USE OF REVOLUTIONS.— In a REVOLUTION, the object is projected on one or more of the regular planes of projection. However, instead of being placed in normal position, the object is revolved on an axis perpendicular to one of the regular planes.

Figure 5-27, view B, is a three-view multi-view projection showing the block in 5-27, view A, as it would appear if it were revolved 30 degrees on an axis perpendicular to the profile plane of projection. Figure 5-28, view A, shows how the

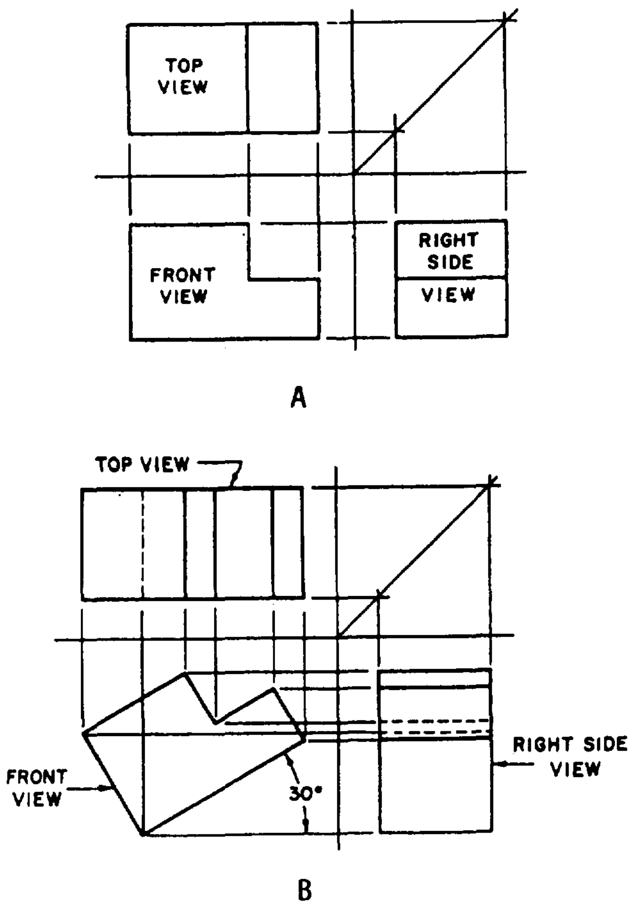


Figure 5-27.-A. Multi-view view of block in normal position; B. Multi-view view of block revolved 30 degrees on axis perpendicular to vertical plane.

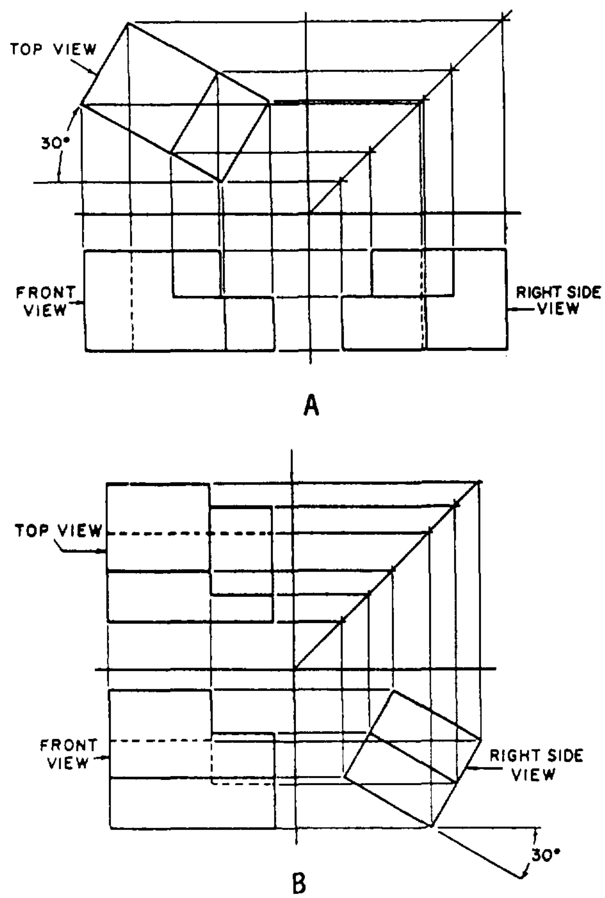


Figure 5-28.-Use of revolution on axis perpendicular to (A) horizontal plane and (B) vertical plane.

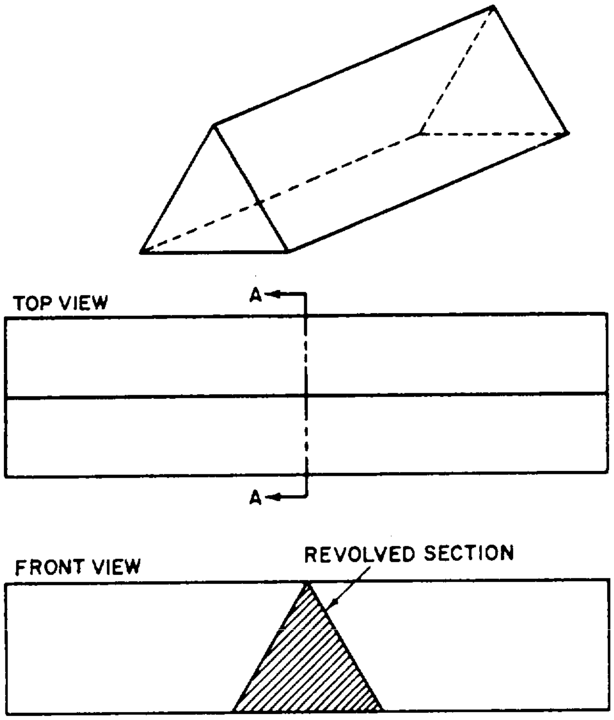


Figure 5-29.-Use of a revolved section (A-A).

block would look if it were revolved 30 degrees on an axis perpendicular to the horizontal plane. Figure 5-28, view B, shows the block as it would appear if it were revolved 30 degrees on an axis perpendicular to the vertical plane.

REVOLVED SECTIONS.— A common use of the revolution is the revolved section, shown in figure 5-29. At the top of this figure, there is a single projection of a triangular block. You can show all required information about this block in a two-view projection by including a revolved section in the front view as shown. You first assume that the block is cut by a plane perpendicular to the longitudinal axis. You then revolve the resulting section 90 degrees on an axis perpendicular to the horizontal plane of projection.

SECTIONING TECHNIQUES.— A sectional view is called for when the internal structure of an object can be better shown in such a view than it can by hidden lines. In the upperpart of figure 5-30, there is a single-view projection of a pulley. The same object is shown below in a two-view multi-view projection. The internal structure of the pulley is shown by the hidden lines in the top view.

In figure 5-31, the internal structure of the pulley is much more clearly shown by a sectional view. Note that hidden lines behind the plane of projection of the section are omitted in the

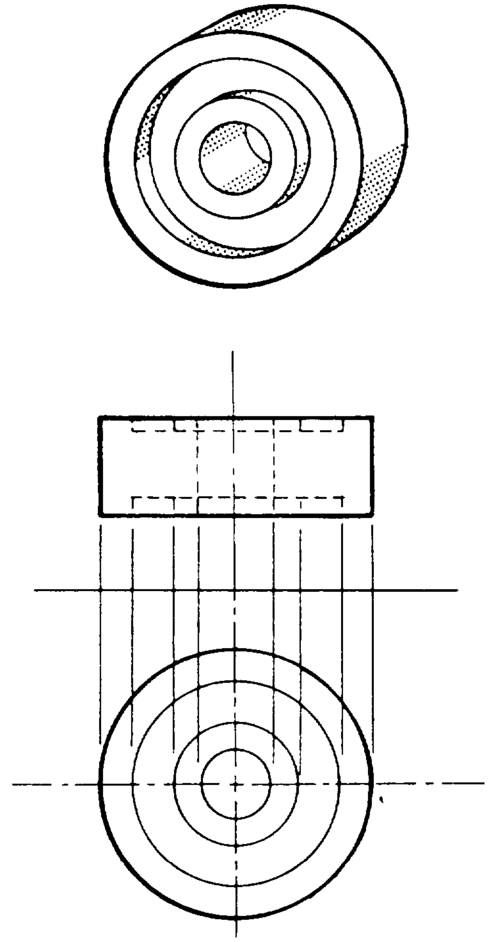


Figure 5-30.-Internal structure of an object shown by hidden lines.

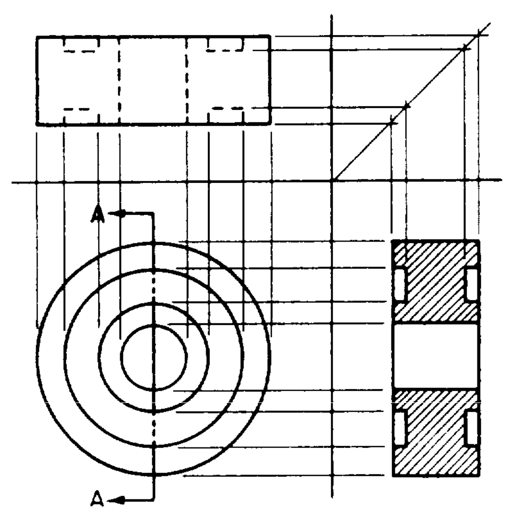


Figure 5-31.-Internal structure of an object more clearly shown by sectional view.

sectional view. These lines are omitted by general custom, the custom being based on the fact that the elimination of hidden lines is the fundamental reason for making a sectional view. However, any lines that would be VISIBLE behind the sectional plane of projection must be included in the sectional view.

The section shown in figure 5-31 is called a FULL SECTION because the cutting plane passes entirely through the object and divides it into two equal parts. Also, the object shown in figure 5-31 is a symmetrical object—meaning, in general, that the shape of one half is identical to the shape of the other. This being the case, you could have used a HALF SECTION like the one shown in figure 5-32. This half section constitutes one half of the full section. Because the other half of the full section would be identical with the half shown, it need not be drawn.

Note that a center line, rather than a visible line, is used to indicate the division between the sectioned and the unsectioned part of the sectional view. A visible line would imply a line that is actually nonexistent on the object. Another term used in place of center line is LINE OF SYMMETRY.

A section consisting of less than half a section is called a PARTIAL SECTION. (See fig. 5-33.) Note that here you use a break line to indicate the division between the sectioned and unsectioned part. For this reason, a partial section is often called a BROKEN SECTION.

The section lines drawn on a sectional surface always serve the basic purpose of indicating the limits of the sectional or cutaway surface. They may also indicate the type of material of which

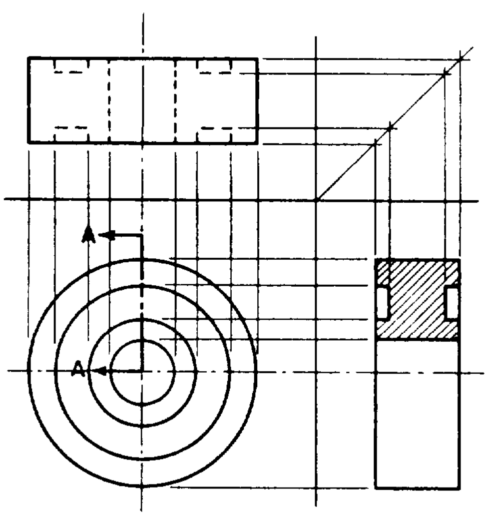


Figure 5-32.-Use of half section.

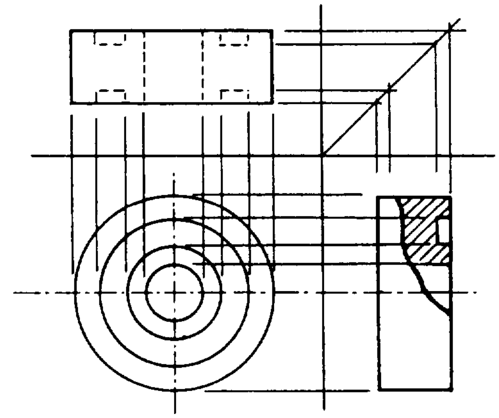


Figure 5-33.-Use of partial or broken section.

the sectioned surface consists. For example, in figure 5-34, view A shows section lining for an object made of cast iron. View B shows two matching parts made of steel, and view C shows three adjacent parts made of brass, bronze, or copper. For other symbolic section lining symbols, refer to ANSI Standard Y14.2.

In view of the vast numbers of different materials, and since drawings must always identify materials by lettered form, such as notes, it is usually more desirable, and it is common practice, to use a general purpose symbol for section lining. The general purpose symbol is the cast iron symbol shown in figure 5-34, view A. The use of other symbols, then, should be limited to those situations when it is truly desirable, or conventional, to graphically differentiate between materials. For example, in an assembly drawing (a drawing showing different papers fitted together), it is often desirable to differentiate materials.

On a regular multi-view section, section lining (sometimes called diagonal hatching or cross-hatching) should be drawn at 45° to the horizontal, as shown in figure 5-34, view A. However, if section liners drawn at 45° to the

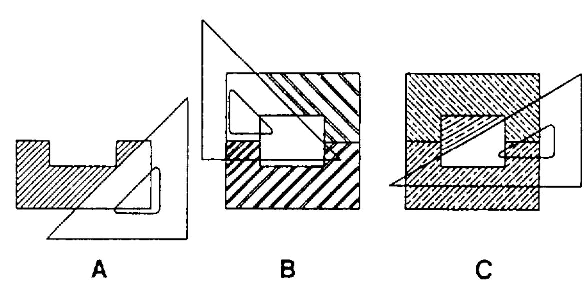


Figure 5-34.-Diagonal hatching on separate sectional surfaces shown in normal position.

horizontal would be parallel or perpendicular (or nearly so) to a prominent visible outline, the angle should be changed to 30°, to 60°, or some other angle. If two adjacent sectioned surfaces are shown, the hatching should be in opposite directions, as shown in figure 5-34, view B. If still a third surface is included, it should be hatched at another suitable angle to make the surface clearly stand out separately from the other surfaces (figure 5-34, view C). Note that the hatching lines on one surface are not permitted to meet those on an adjacent surface.

In drawing section lining, use a sharp, medium-grade pencil (H or 2H). Space the lines as uniformly as possible by eye. As a rule, spacing of the lines should be as generous as possible, yet close enough to distinguish the sectioned surface clearly. For average drawings, space the lines about 3/32 in. or more apart.

Diagonal hatching on an auxiliary section should be drawn at 45 degrees to the horizontal, with respect to the section. Figure 5-35 shows this rule.

In a revolution or other view of an object in other than the normal position, the diagonal hatching on a section should be drawn at 45 degrees to the horizontal or vertical axis of the object as it appears in the revolution. Figure 5-36 shows this rule.

Axonometric Projection

Axonometric single-plane projection is another way of showing an object in all three dimensions in a single view. Theoretically, axonometric projection is orthographic projection in that only one plane is used and the projection lines are perpendicular to the plane of projections. It is the object itself, rather than the projection lines, that is inclined to the plane of projection.

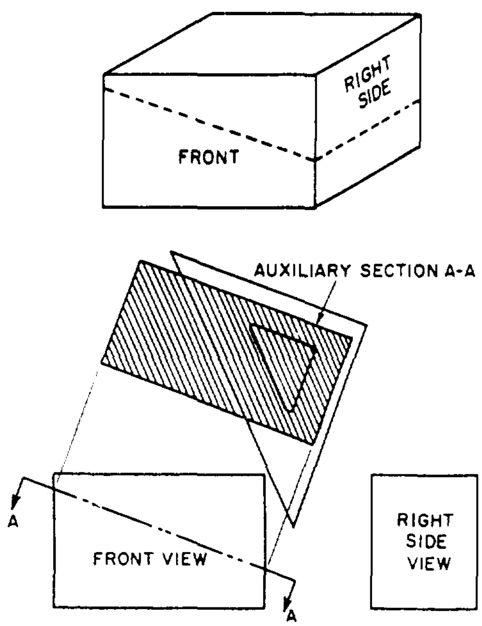


Figure 5-35.-Diagonal hatching on an auxiliary section.

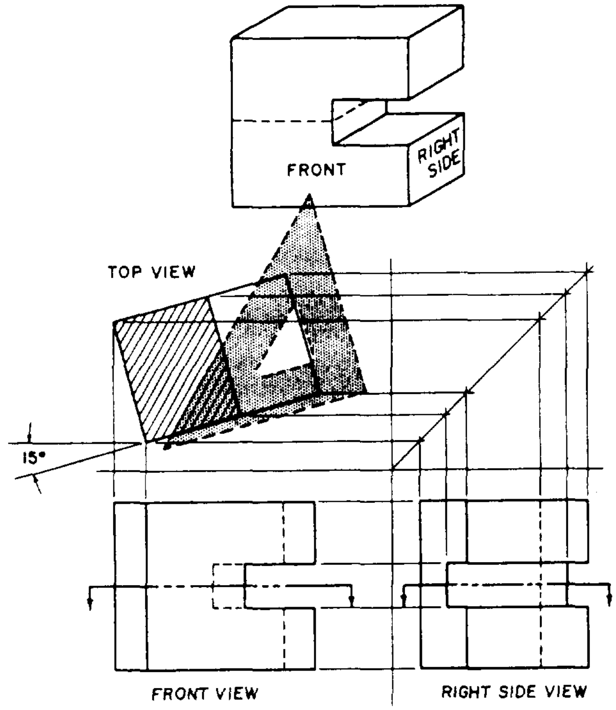


Figure 5-36.-Diagonal hatching on a revolution.

ISOMETRIC PROJECTION AND ISOMETRIC DRAWING.— Figure 5-37 shows a cube projected by ISOMETRIC PROJECTION, the most frequently used type of axonometric projection. The cube is inclined so that all of its surfaces make the same angle (35°16′) with the plane of projection. As a result of this inclination, the length of each of the edges shown in the projection is somewhat shorter than the actual length of the edge on the object itself. This reduction is called FORESHORTENING. The degree of reduction amounts to the ratio of 1 to the cosine of 35°16′, or 1/0.8165. This means that if an edge on the cube is 1 in, long, the projected edge will be 0.8165 in. long. As all of the surfaces make the same angle with the plane of projection, the edges all foreshorten in the same ratio. Therefore, one scale can be used for the entire layout; hence the term *isometric,* which literally means "one-scale."

Figure 5-38 shows an isometric projection as it would look to an observer whose line of sight was perpendicular to the plane of projection. Note

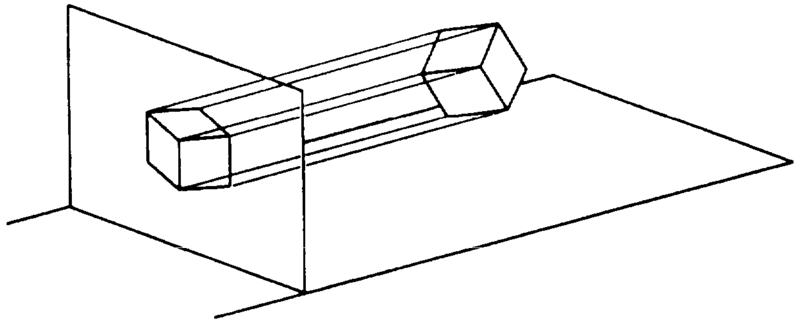


Figure 5-37.-Isometric projection of a cube.

that the figure has a central axis, formed by the lines OA, OB, and OC. The existence of this axis is the origin of the term *axonometric projection*. In an isometric projection, each line in the axis forms a 120-degree angle with the adjacent line, as shown. A quick way to draw the axis is to draw the perpendicular OC, then use a T square and 30°/60° triangle to draw OA and OB at 30 degrees to the horizontal. Since the projections of parallel lines are parallel, the projections of the other edges of the cube will be, respectively, parallel to these axes.

A rectangular object can be easily drawn in isometric by the procedure known as box construction. In the upperpart of figure 5-39, there is a two-view normal multi-view projection of a rectangular block. An isometric drawing of the block is shown below. You can see how you build the figure on the isometric axis and how you lay out the dimensions of the object on the isometric drawing. Because you lay out the identical dimensions, it is an isometric drawing rather than an isometric projection.

Non-isometric Lines.— If you examine the isometric drawing shown in figure 5-39, you will note that each line in the drawing is parallel to one or another of the legs of the isometric axis. You will also notice that each line is a normal line in the multi-view projection. Recall that a normal line is a line that, in a normal multi-view projection, is parallel to two of the planes of projection and perpendicular to the third. Thus,

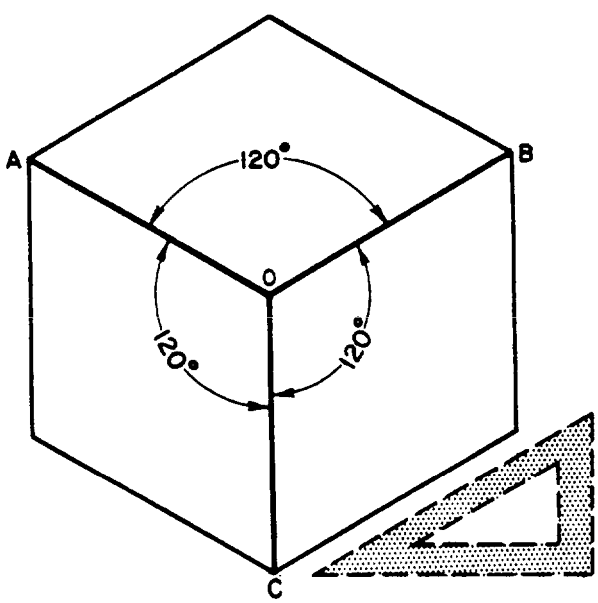


Figure 5-38.-Use of an isometric axis.

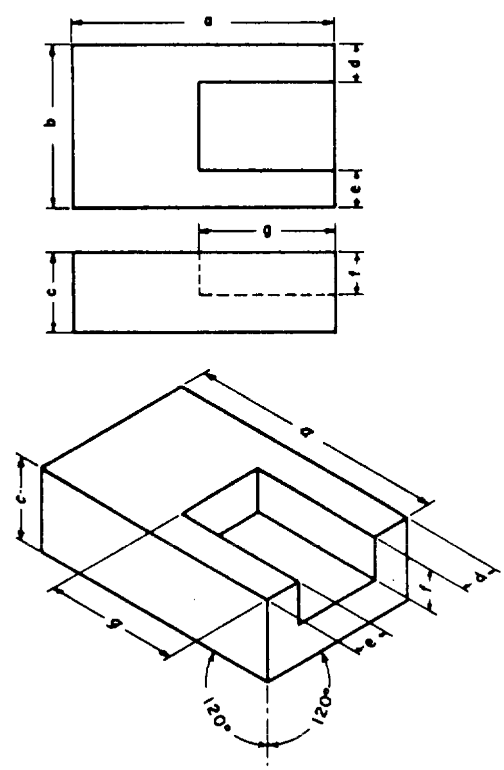


Figure 5-39.-Use of "box construction" in isometric drawing.

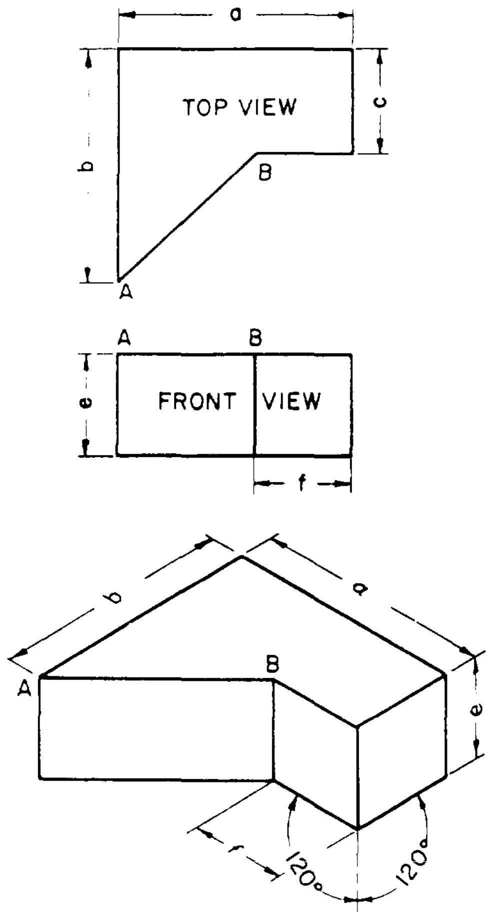


Figure 5-40.-A non-isometric line (AB) in an isometric projection.

a NON-ISOMETRIC LINE is a line that is not parallel to any one of the three legs of the isometric axis. It is not a normal line in a normal multi-view projection of the object.

The upperpart of figure 5-40 shows a two-view normal multi-view projection of a block. Though the line AB is parallel to the horizontal plane of projection, it is oblique to both the vertical and the profile planes. It is therefore not a normal, but an oblique, line in the multi-view projection, and it will be a non-isometric line in an isometric projection or drawing of the same object.

The line AB appears in its true length in the top multi-view view because it is parallel to the plane of the view (the horizontal plane); but it will appear as a non-isometric line, and therefore not in its true length, in an isometric drawing, as shown in the bottom part of figure 5-40. It follows that you cannot transfer AB directly from the multi-view projection to the isometric drawing. You can, however, transfer directly all the normal lines in the multi-view projection, which will be isometric lines appearing in their true lengths in the isometric drawing. When you have done this, you will have constructed the entire isometric drawing, exclusive of line AB and of its counterpart on the bottom face of the block. The end points of AB and of its counterpart will be located, however, and it will only be necessary to connect them by straight lines.

Angles in Isometric.—In a normal multi-view view of an object, an angle will appear in its true size. In an isometric projection or drawing, an angle never appears in its true size, Even an angle formed by normal lines, such as each of the 90-degree corner angles of the block shown in the bottom part of figure 5-41, appears distorted in isometric.

The same principle used in transferring a non-isometric line is used to transfer an angle in isometric. The upperpart of figure 5-41 shows a two-view multi-view projection of a block. On the top face of the block, the line AB makes a 40-degree angle with the front edge. The line AB is an oblique (that is, not normal) line, which will appear as a non-isometric line in the isometric drawing. You locate the end points of AB on the isometric drawing by

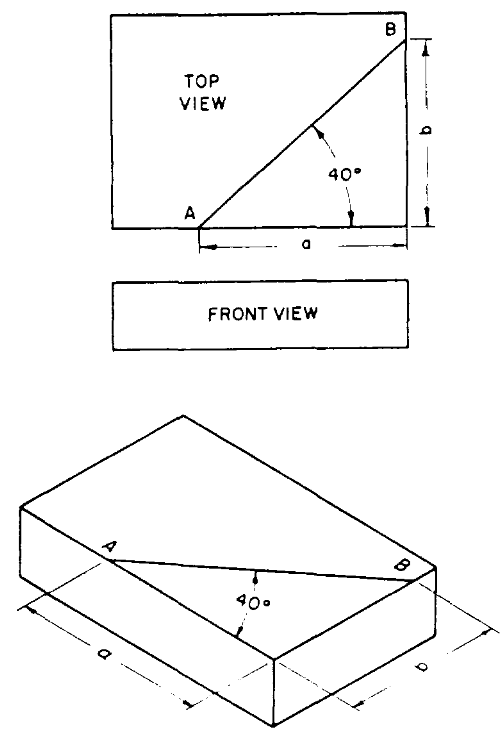


Figure 5-41.-Drawing an angle in isometric.

measuring distances along normal lines on the multi-view projection and laying them off along the corresponding isometric lines on the isometric drawing. The angle that measures 40 degrees on the top multi-view view measures only about 32 degrees on the isometric drawing. Note, however, that it is labeled 40 degrees on the isometric drawing. This is because it actually is a 40-degree angle as it would look on a surface plane at the isometric angle of inclination.

Circles in Isometric.— A circle in a normal multi-view view will appear as an ellipse in an isometric drawing. This is shown in figure 5-42, view A.

A procedure that maybe used to construct an isometric circle is shown in figure 5-42, view B. The steps of that procedure are as follows:

1. Draw the isometric center lines of the circle. Then, using those center lines, lay off an isometric square with sides equal to the diameter of the circle.
2. From the near corners of the box, draw bisectors to the opposite intersections of the center lines and the box. The bisectors will intersect at four points (A, A´, B, B´), which will be the centers of four circular arcs.
3. Draw two large arcs with radius R, using Points A and A´ as centers, Draw the two smaller arcs with radius r, using Points B and B´ as centers.

If the above discussion seems familiar, it should. It is simply an approximation of the four-point method you studied in the previous chapter. However, it can be used only when drawing isometric circles on an isometric drawing.

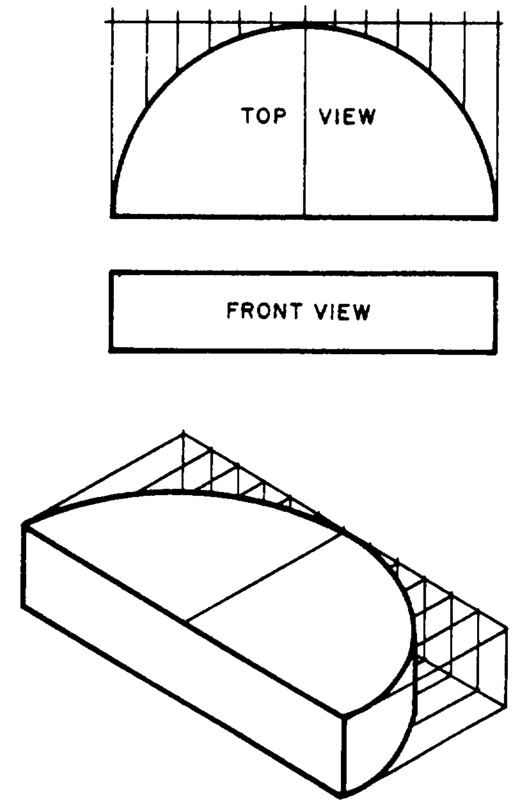


Figure 5-43.-Method of drawing a noncircular curve in isometric.

Noncircular Curves in Isometric.— A line that appears as a noncircular curve in a normal multi-view view of an object appears as a non-isometric line in an isometric drawing. To transfer such a line to an isometric drawing, you must plot a series of points by measuring along normal lines in the multi-view view and transferring these measurements to corresponding isometric lines in the isometric drawing.

The upperpart of figure 5-43 shows a two-view multi-view projection of a block with

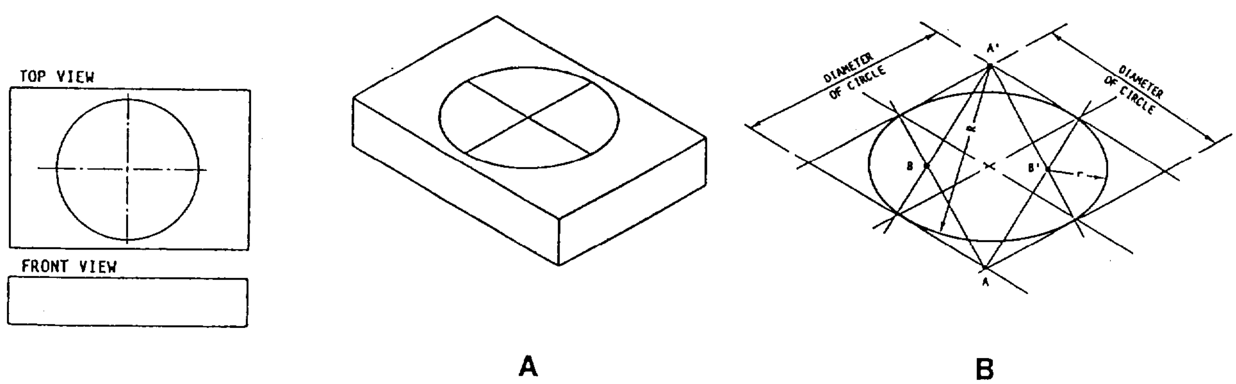


Figure 5-42.-A circle on a normal multi-view view appears as an ellipse in an isometric drawing.

an elliptical edge. To make an isometric drawing of this block, draw the circumscribing rectangle on the top multi-view view, lay off equal intervals as shown, and draw perpendiculars at these intervals from the upper horizontal edge of the rectangle to the ellipse. Then draw the rectangle in isometric, as shown below, and plot a series of points along the elliptical edge by laying off the same perpendiculars shown in the top multi-view view. Draw the line of the ellipse through these points with a french curve.

Alternate Positions of Isometric Axis.— Up to this point, the isometric axis has been used with the lower leg vertical. The axis may, however, be used in any position, provided the angle between adjacent legs is always 120 degrees. Figure 5-44 shows how varying the position of the axis varies the view of the object.

Diagonal Hatching in Isometric.— Diagonal hatching on a sectional surface shown in isometric should have the appearance of making a 45-degree angle with the horizontal or vertical axis of the surface. If the surface is an isometric surface (one that makes an angle of 35°16’ with the plane of projection), lines drawn at an angle of 60 degrees to the horizontal margin of the paper, as shown in figure 5-45, present the required appearance. To show diagonal hatching on a non-isometric surface, you must experiment to determine the angle that presents the required appearance.

DIMETRIC AND TRIMETRIC PROJECTION.— TWO other subclassifications of the axonometric projection category are dimetric and trimetric projections; however, these types are used less frequently than isometric projections and will not be discussed further in this training manual.

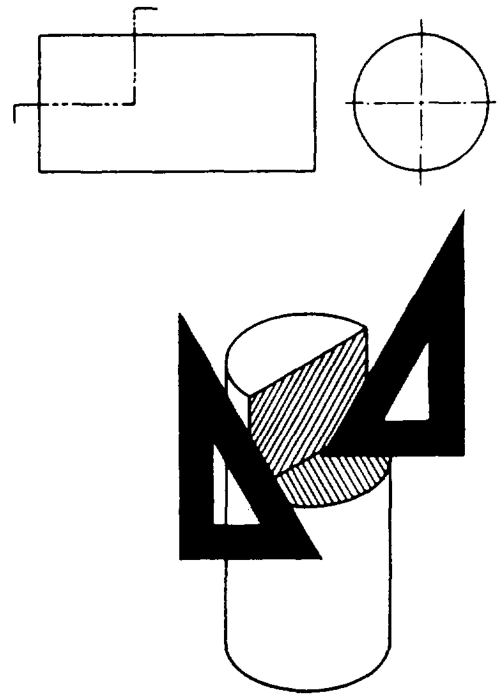


Figure 5-45.-An example of diagonal hatching in isometric.

OBLIQUE SINGLE-PLANE PROJECTION

We have seen that an object may be drawn showing length and width on a single plane. Depth

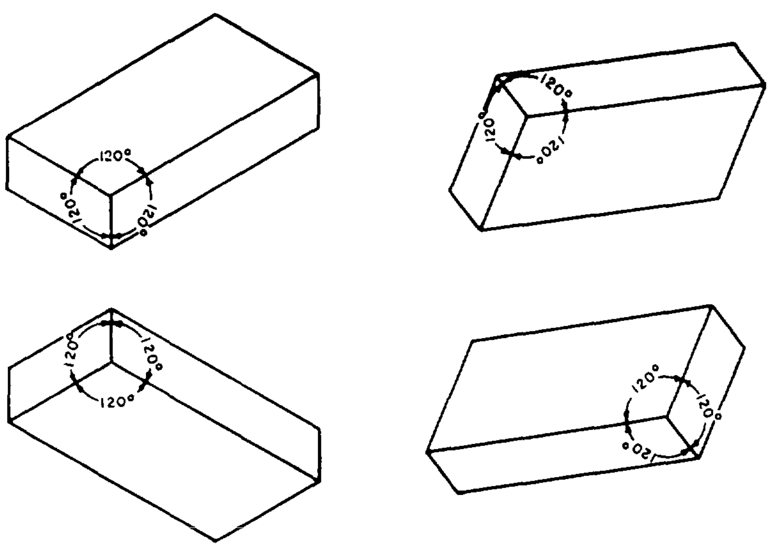


Figure 5-44.-Various positions of isometric axes.

may also be shown on this single plane by constructing the receding projection lines of the object at an angle other than perpendicular to the plane of projection.

Figure 5-46 shows the same object by both orthographic and oblique projection. The block is placed so that its front surface (the surface toward the plane of projection) is parallel to the plane of projection. You can see that the orthographic projection shows only this surface of the block. The oblique projection, on the other hand, shows the front surface and also the top and side surfaces. The orthographic projection shows only two dimensions: length and width. The oblique projection shows three: length, width, and thickness. Oblique projection, then, is one method by which an object can be shown, in a single view, in all three dimensions.

There are two types of oblique single-plane projections: CAVALIER and CABINET.

Cavalier Projection

CAVALIER PROJECTION is a form of oblique projection in which the projection lines are presumed to make a 45-degree vertical and a 45-degree horizontal angle with the plane of projection. Assume that in figure 5-47 the line XX' represents a side-edge view of the plane of projection, and that the square ABCD represents a side of a cube, placed with its front face parallel to, and its top face perpendicular to, the plane of projection. You can see that the projected lengths of AB and AD are the same as the actual lengths.

Now assume that the line XX' in figure 5-47 represents a top-edge view of the plane of projection, and that the square ABCD represents the top of the cube. You can see again that the projected lengths of AB and AD are the same as the actual lengths of AB and AD.

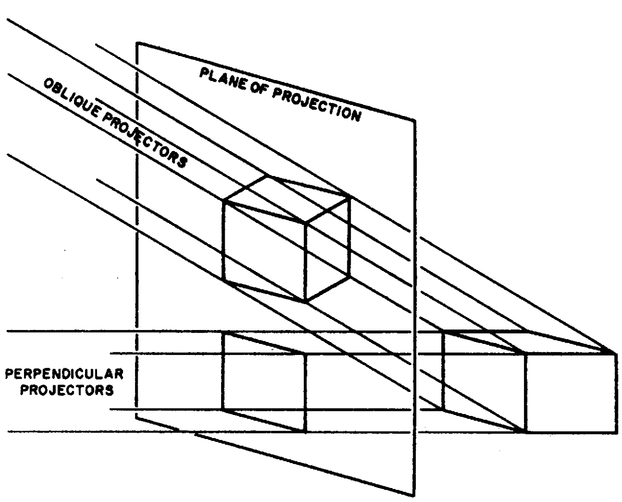


Figure 5-46.—Oblique and orthographic projections of the same object.

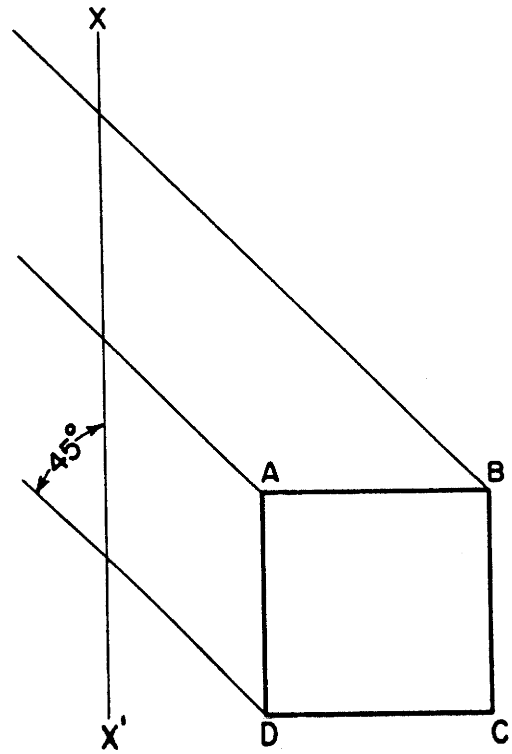


Figure 5-47.—Angle of projection lines in a cavalier projection.

In a cavalier projection, then, any line parallel to or perpendicular to the plane of projection is projected in its true length. Figure 5-48 shows a cavalier projection of the cube shown in figure 5-47. You start by drawing the axis, which consists of the front axes OA and OB and the receding axis OC. The front axes are always perpendicular to each other; the receding axis

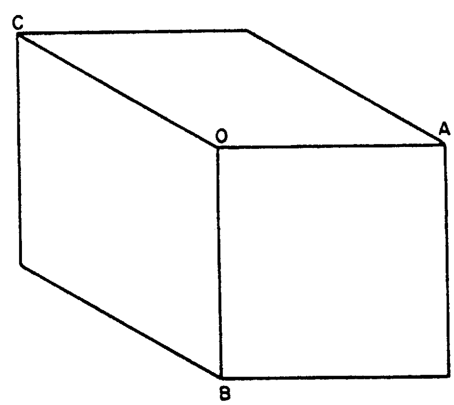


Figure 5-48.—Cavalier projection of a cube.

may be drawn from O at any convenient angle. All three are equal in length, the length being the length of an edge of the original cube (which may be scaled down or up if the drawing is made other than full scale). After you draw the axis, complete the projection by drawing the required parallel lines. All the edges shown in the projection are, like the edges on the original cube, equal in length.

Cabinet Projection

The first thing you notice about the cube shown in figure 5-48 is the fact that it doesn't look like a cube because the depth dimension appears to be longer than the height and width dimensions. The reason for this is the fact that a cavalier projection corrects a human optical illusion—the one that causes an object to appear to become smaller as its distance from the eye increases. This illusion. in turn. causes receding parallel lines to appear to the eye to be shorter-than they really are, and also to be converging toward a point in the distance. But receding parallel lines on a cavalier projection appear in their true lengths, and they remain constantly parallel. Also, the far edges of the cube shown in figure 5-48 are equal in length to the near edges.

The distortion in figure 5-48 is only apparent. It is sometimes desirable to reduce this appearance of distortion. This can be done by reducing the length of the receding axis (OC in fig. 5-39). This axis can be reduced by any desired amount, but it is customary to reduce it by one half.

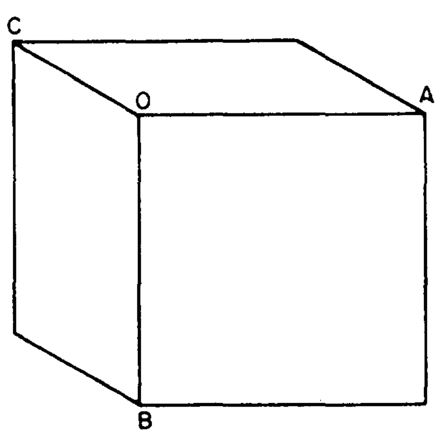


Figure 5-49.-Cabinet projection of the cube in figure 5-48. (Note receding axis OC reduced by one half its length.)

When the receding axis is reduced by one half, the projection is called a CABINET PROJECTION. Figure 5-49 shows a cabinet projection of a cube. The length of the receding axis OC has been reduced by one half. As you can see, this representation looks more like a cube.

Cavalier and cabinet projections are compared in figures 5-50 and 5-51.

Oblique Drawing Techniques

In an oblique projection drawing of a rectangular object, one face (usually the most prominent or most important) is parallel to the plane of projection. All features appearing on this plane, such as circles or oblique lines, are in their true dimension. However, in the side or top views, these same features are somewhat distorted because of the receding axis angle. When drawing these features, you can use various techniques to aid you in their construction.

For convenience, the angles chosen for the receding axis are either 30 degrees, 45 degrees, or

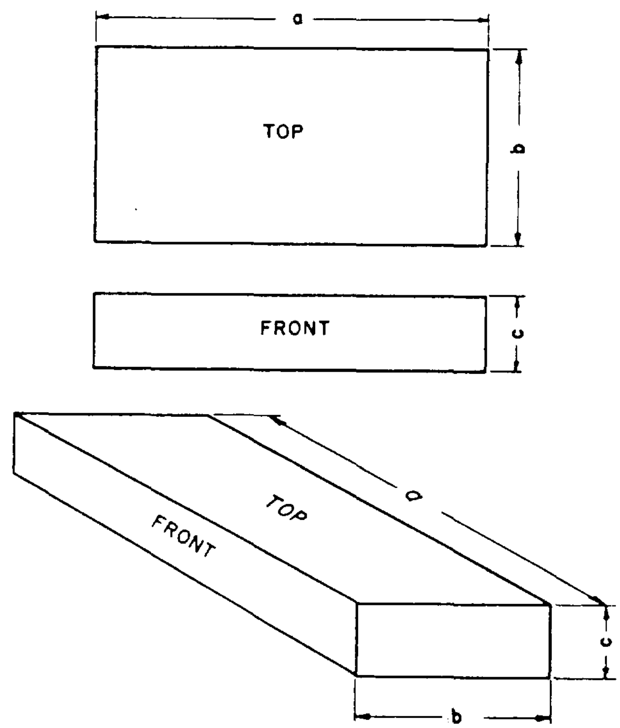


Figure 5-50.-Cavalier projection. Distances along front axis and along receding axis are all true.

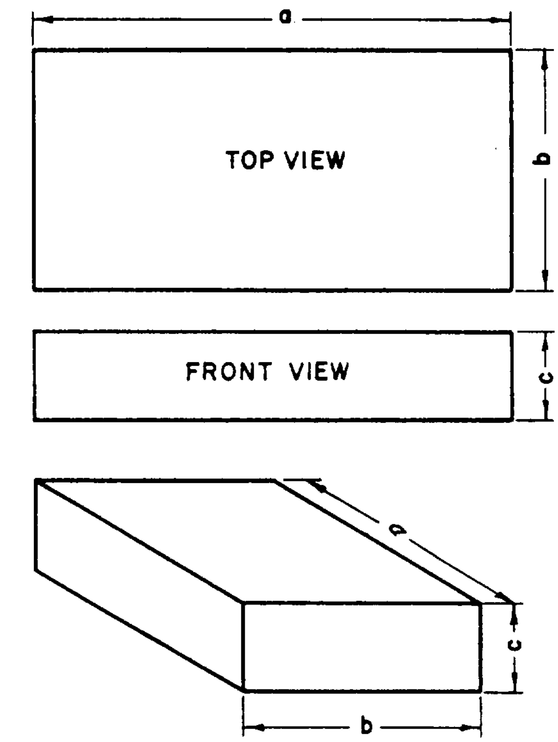


Figure 5-51.-Cabinet projection. Distances along front axis are true; distances along receding axis are reduced by one half.

60 degrees because they are easily constructed with triangles (fig. 5-52).

IRREGULAR LINES.— An irregular line in an oblique drawing is a line that would be an oblique line in a normal multi-view projection. In the upperpart of figure 5-53, there is a

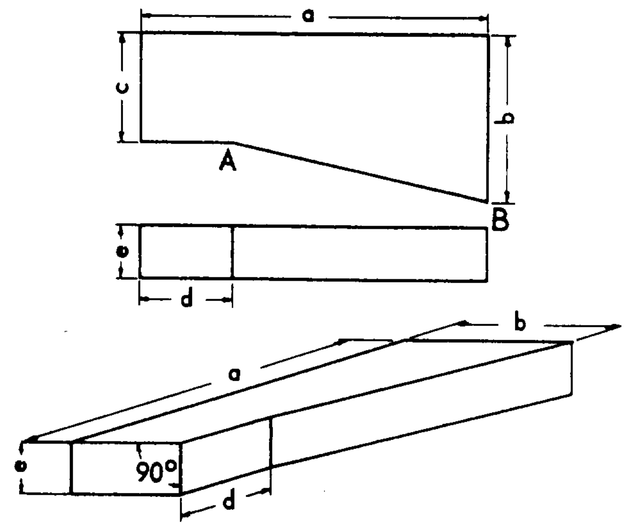


Figure 5-53.-Cavalier projection of an object with irregular lines.

two-view multi-view projection of a block; the line AB is an irregular line and will not appear in its true length in an oblique projection. To transfer the line, you draw the projection by transferring measurements taken along regular lines; these measurements locate the end points of the irregular line. Figure 5-53 shows the cavalier projection of an irregular line. The procedure for cabinet projection would be the same except that all measurements along the receding axis would be reduced by one half.

ANGLES IN OBLIQUE.— In an oblique projection, an angle on the surface that is parallel to the plane of projection will appear in its true

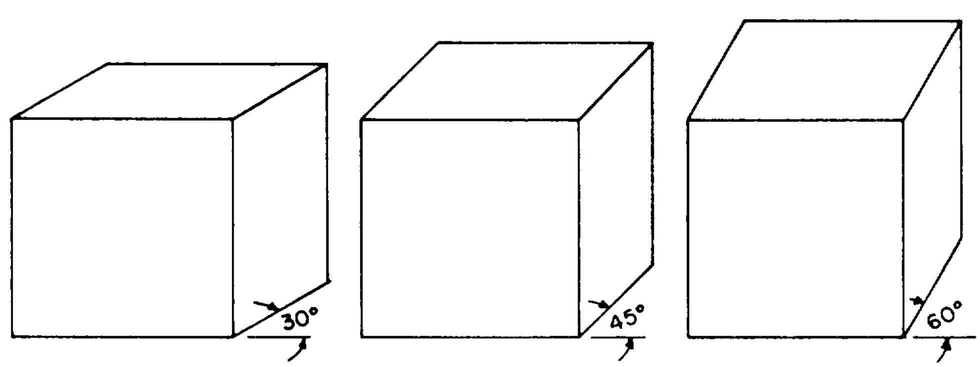


Figure 5-52.-Angles of 30 degrees, 45 degrees, and 60 degrees are normally chosen for the receding axis in oblique projection because they are easily drawn with triangles.

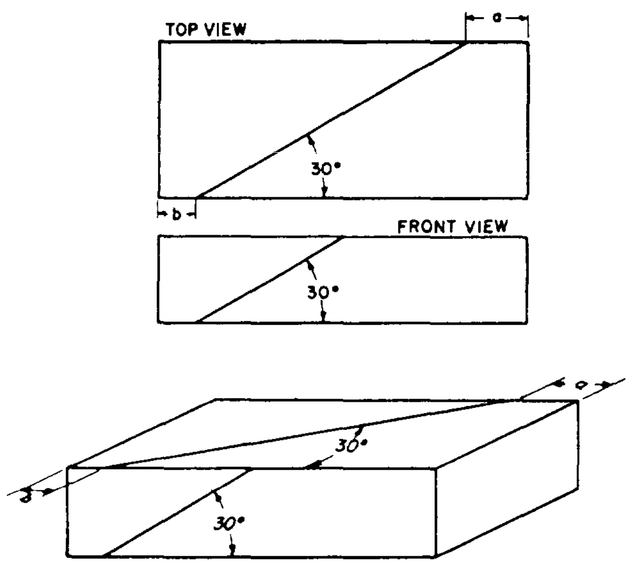


Figure 5-54.-Transferring an angle in oblique projection.

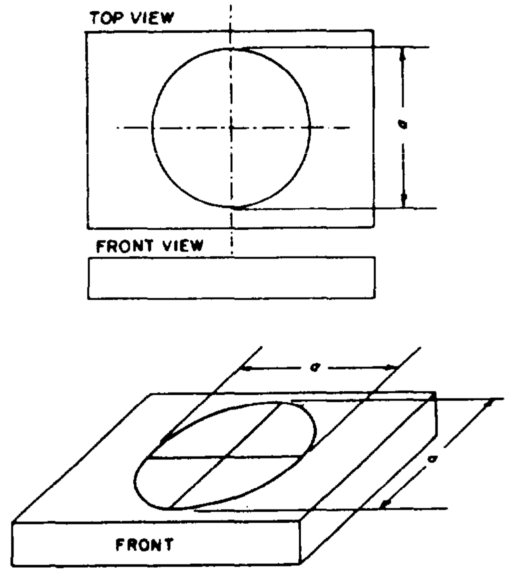


Figure 5-55.-Cavalier projection of a circle on a receding surface.

size; an angle on any other surface will not. The upperpart of figure 5-54 shows a two-view multi-view projection of a block. It has a 30-degree angle on the top face and another on the front face. In the cavalier projection below, the angle on the front face still measures 30 degrees; that on the top face measures only about 9 degrees. You transfer the top face angle by locating the end points of the line by measurements along regular lines.

CIRCLES IN OBLIQUE.— In an oblique projection, a circle on the surface parallel to the plane of projection will appear as a circle. A circle on any other surface will appear as an ellipse, as shown in figure 5-55. The upperpart of this figure shows a two-view multi-view projection of a block with a circle on its upper face. The lower part of this figure shows a cavalier projection in which the circle appears as an ellipse. Each of the conjugate (joined together) diameters of the ellipse is equal to the diameter of the circle.

PERSPECTIVE PROJECTION AND PERSPECTIVE DRAWING

PERSPECTIVE PROJECTION (fig. 5-2) is obtained when the projection lines converge to a point that is at a finite distance from the plane of projection. Each projection line forms a different angle with the plane of projection, giving the viewer a three-dimensional picture of the object. This type of projection, however, cannot accurately convey the structural features of a building; hence, it is not adequate for working drawings.

On the other hand, of all the three-dimensional single-plane drawings, PERSPECTIVE DRAWINGS are the ones that look the most natural. At the same time, they are also the ones that contain the most errors. Lines that have the same length on the object have different lengths on the drawing. No single line or angle on the drawing has a length or size that has any known relationship to its true length or size when projected through perspective projections.

Perspective drawing is used only in drawings of an illustrative nature, in which an object is deliberately made to appear the way it looks to the human eye. Most of the drawings you will prepare will be drawings in which accuracy, rather than eye appearance, will be the chief consideration. Consequently, you will not be concerned much with perspective drawing.

If you are required to prepare perspective drawings, refer to *Illustrator Draftsman*, NAVEDTRA 10472, or civilian publications, such as *Architectural Drawing and Light Construction* and *Architectural Graphic Standards*.

SKETCHING

The EA who is able to make quick, accurate SKETCHES will find this ability a valuable asset when it comes to conveying technical information or ideas. Without this ability you are handicapped in many of your day-to-day situations. Almost every drawing or graphic problem originates with a sketch. The sketch becomes an important thinking instrument, as well as a means of conversing effectively with technically trained people. Sketching is not just another trick of the trade; it is a skill that is essential and should be an important part of your training. To gain proficiency in freehand sketching, invite situations entailing sketching at every opportunity. Do not worry about your first attempts at sketching; appearance will improve with experience.

A sketch is usually thought of as being made freehand, although in practice you may use graph paper or a small triangle for a straightedge. A sketch may be of an object or an idea or a combination of both. Sketches are used to solve graphic problems before an object or structure is put in final form on a drawing. Preliminary sketches are used to plan and organize intelligently the sheet layout of a complete set of drawings for a construction project, which often includes many views and details. There are no set standards for technical freehand sketching; however, you should use standard line conventions for clarity.

A sketch may be drawn pictorially so that it actually looks like the object, or it can be an orthographic sketch of the object showing different views. The degree of perfection required for any sketch will depend upon its intended use.

SKETCHING MATERIALS

One of the main advantages of sketching is that few materials are required. Basically, you need only a pencil and paper. However, the type of sketch prepared and your personal preference will determine the materials used.

You should use a soft pencil in the grade range from F to 3H, with H being a good grade for most sketching. The pencil should be long enough to permit a relaxed but stable grip. As you gain experience, you may even prefer to use fine tip felt pens. (Dark- or bright-colored pens should be used.) Felt tip pens work very well on overlay sketches (discussed later).

Most of your sketches will be done on scratch paper, which can be any type or size of paper. An experienced draftsman will keep a pad of 3 in. by 5 in. or 5 in. by 8 in. scratch paper handy at all times. For planning the layout of a drawing, you will find tracing paper to be convenient. The advantage of sketching on tracing paper is the ease with which sketches can be modified or redeveloped simply by placing transparent paper over previous sketches or existing drawings. Sketches prepared in this manner are referred to as OVERLAY SKETCHES. Cross-section or graph paper may be used to save time when you are required to draw sketches to scale. (See fig. 5-56.) Isometric sketches are easily done on specially ruled isometric paper. (See fig. 5-57.)

An eraser maybe used, but you will probably do very little erasing. Sketches usually can be

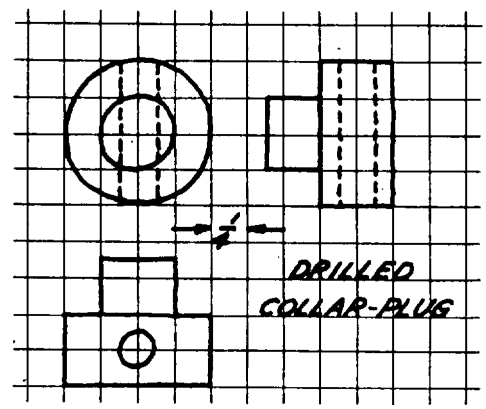


Figure 5-56.-Use of cross-sectional paper in technical sketching.

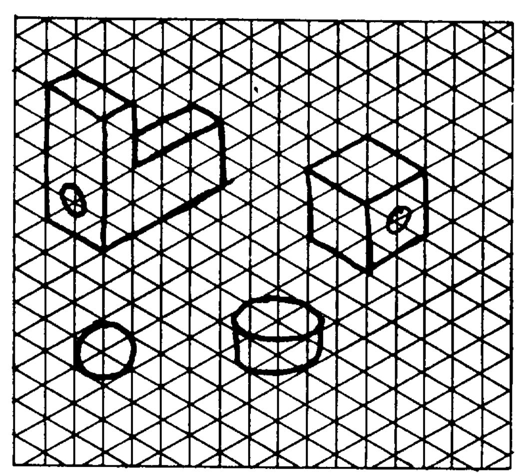


Figure 5-57.-Use of specially ruled isometric paper in technical sketching.

redrawn more quickly than mistakes can be erased.

For making dimensioned sketches in the field, you will need some sort of measuring tape—either a pocket rule or a surveyor's tape, depending on the extent of the measurements taken. If you are required to collect extensive field data, it would be to your benefit to maintain a sketch notebook. A surveyor's field notebook works well for this purpose.

TECHNIQUES OF SKETCHING

The sketch should conform to one of the standard types of projection discussed in this chapter. You must apply correct proportion whenever possible. When you use cross-section paper, its grid will provide a ready scale that will aid you in sketching proportionally. You do this by counting the squares within the object to be drawn. The size of your sketch depends upon the complexity of the object and the size of paper you are using.

Sketching Straight Lines

In sketching lines, place a dot where you want a line to begin and one where you want it to end. In sketching long lines, place one or more dots between the end dots. Then swing your hand in the direction your line should go, and back again a couple of times before you touch your pencil to the paper. In this way you get the feel of the line. Then use these dots to guide your eye and your hand as you draw the line. Draw each line with a series of short strokes instead of with one stroke. Using short strokes, you can better control the direction of your line and the pressure of your pencil on the paper. Hold the pencil about three quarters of an inch to an inch from the point so that you can see what you are doing. Strive for a free and easy movement rather than a cramped finger and wrist movement.

Another useful technique in drawing straight lines is to use the side of the paper, pad, or table as a guide for your hand. Hold the pencil at the desired starting point of the line and place the heel of your hand and one finger on the guide, as shown in figure 5-58. Move the pencil, in this case, with one uniform stroke to complete the line. Try drawing several light horizontal lines and, after each one is drawn, examine it for straightness, weight, and neatness. If it is too light, use either a softer pencil or a little more pressure.

Vertical lines are usually sketched downward on the paper. The same suggestions for using locator dots, free movement of the entire arm, and guides apply to vertical lines as they do to horizontal lines.

Slanting lines may be drawn from either end toward the other. For better control, you might find it helpful to rotate the paper, thus placing the desired slanting line in either the horizontal or vertical position.

To keep your sketch neat, first sketch your lines lightly. Lines not essential to the drawing can be sketched so lightly that you need not erase them. Darken essential lines by running your pencil over them with more pressure. Figure 5-59 shows line conventions drawn with various types of pencil points.

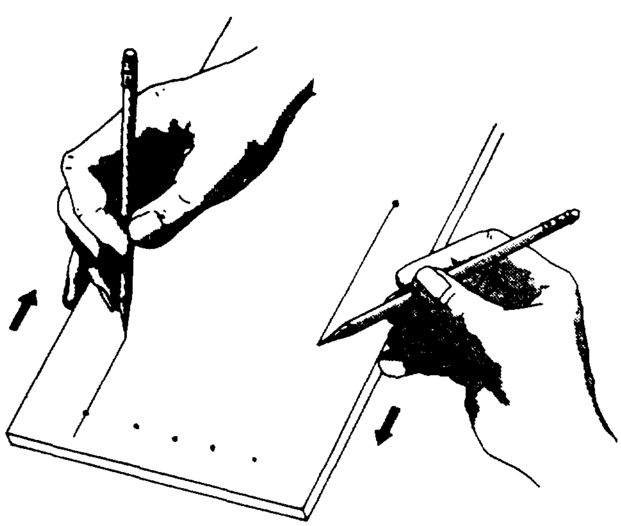


Figure 5-58.-Use of paper, pad, or table as a guide when drawing straight lines.

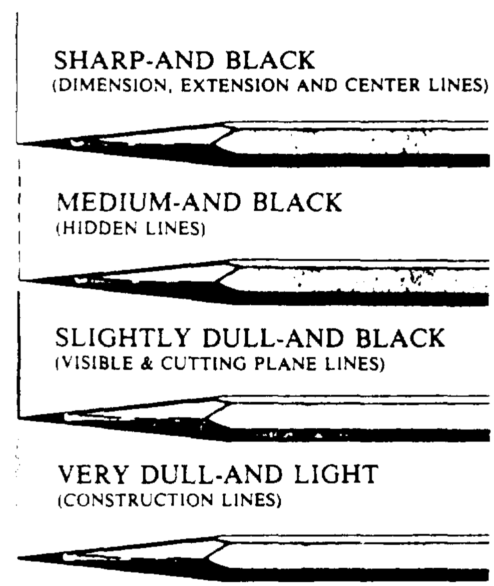


Figure 5-59.-Line conventions drawn with various types of pencil points.

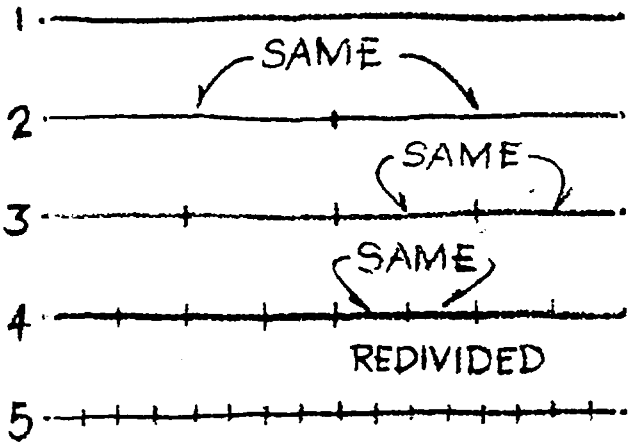


Figure 5-60.-Bisecting a line by visual comparison.

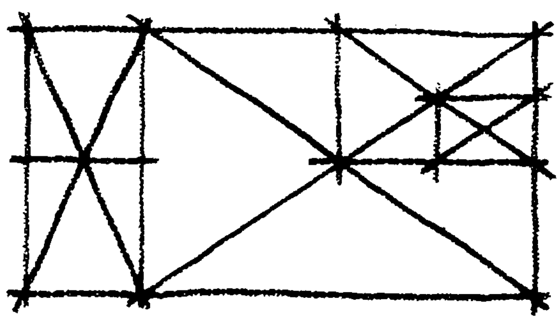


Figure 5-61.-Locating centers by sketching diagonals.

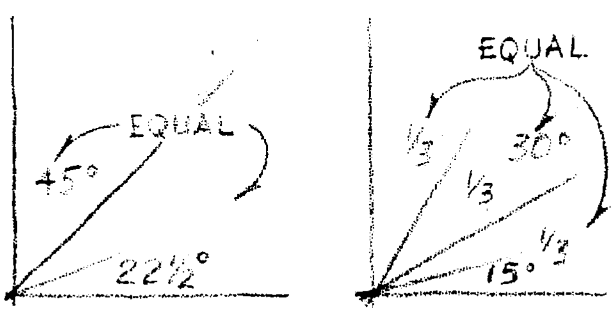


Figure 5-62.-Sketching angles by visual comparison.

Dividing Lines and Areas Equally

Your ability to divide lines and areas into equal parts is necessary in arriving at many of the common geometric forms required in sketching. The simplest method of bisecting lines is by visual comparison, as shown in figure 5-60. The entire line is first observed and weighed optically to determine its fulcrum or point of balance. Each half is compared visually before the bisecting point is placed. This procedure can be repeated any number of times to divide a line into any number of equal divisions, merely by dividing and redividing its line segments.

Centers of rectangular areas are easily determined by drawing their diagonals. If necessary the halves can be divided with diagonals for smaller divisions, as shown in figure 5-61.

Sketching Angles

The 90-degree angle is predominant in the majority of your sketches. Thus it is important that you learn to sketch right angles accurately, even if it entails checking them with the triangle occasionally. Frequently, the perpendicular edges of your paper can serve as a visual guide for comparison. It is also helpful to turn your sketch upside down; non-perpendicular tendencies of horizontal and vertical lines will become evident. Shaping right angles correctly will give your sketch stability, without which effectiveness is lost.

A 45-degree angle is made by dividing a right angle by visual comparison; and a 30-degree or 60-degree angle, by dividing the right angle into three equal parts. The 30-degree or 45-degree angle may be divided into equal parts in the same manner. (See fig. 5-62.) Always start with the right angle for the most accurate estimation of angle shape.

Sketching Circles and Arcs

Perfectly round circles are the most difficult to draw freehand. Figure 5-63 shows methods of

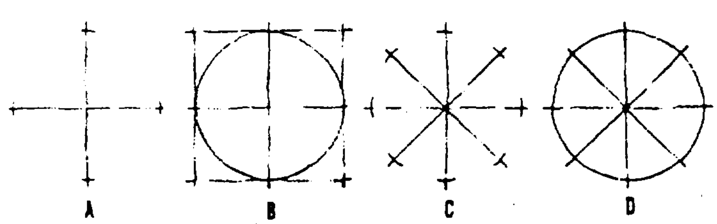


Figure 5-63.-Methods of sketching circles.

drawing circles and curves using straight lines as construction lines. First, draw two straight lines crossing each other at right angles, as in figure 5-63, view A. The point at which they cross will serve as the center of the circle. The four lines radiating from this center will serve as the radii of the circle. You can use a piece of marked scrap paper to measure an equal distance on each radius from the center. Sketch a square, with the center of each side passing through the mark defining a radius. (See fig. 5-63, view B.) Now sketch in your circle, using the angles of the square as a guide for each arc. When larger circles are required, you can add 45-degree angles to the square to form an octagon. This will provide four additional points of tangency for the inscribed circle.

In figure 5-63, view C and view D, four lines, instead of two, are sketched crossing each other. The radii are measured as in constructing the other circle, but a square is not drawn. For this method, you will find it helpful to rotate the paper and sketch the circle in one direction.

For drawing large circles, you can make a substitute for a compass with a pencil, a piece of string, and a thumbtack. Tie one end of the string to your pencil near the tip. Measure the radius of the circle you are drawing on the string, and insert your tack at this point. Now swing your pencil in a circle, taking care to keep it vertical to the paper.

Another technique for drawing circles is shown in figure 5-64. In view A of figure 5-64, observe how the pencil is held beneath the four fingers with the thumb. This grip tends to produce a soft or easy motion for sketching large circles or curves and also makes it possible to sketch small circles, as shown in figure 5-64, views B and C. You notice in figure 5-64, view B, that the second finger rests at the center of the circle and forms the pivot about which the pencil lead can swing. The distance from the fingertip to the pencil lead determines the radius of the circle. To draw smaller circles, you need to assume a somewhat different grip on the pencil, as shown in view C of figure 5-64, but the principle is the same.

As shown in view A of figure 5-65, the first step in sketching either large or small circles with the grips shown in the previous figure is placing the second finger on the paper at the center of the proposed circle. Then, with the pencil lightly touching the paper, use the other hand to rotate the paper to give you a circle that may look like the one in figure 5-65, view B. To correct the slight error of closure shown in view C, erase a substantial section of the circle and correct it by eye, as shown at the right. You now have a complete and round circle, but with only a very light line,

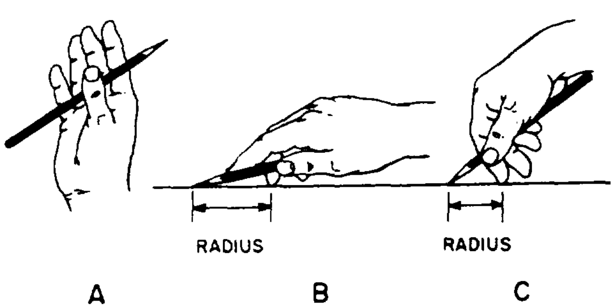


Figure 5-64.-Proper pencil grip in sketching circles and arcs.

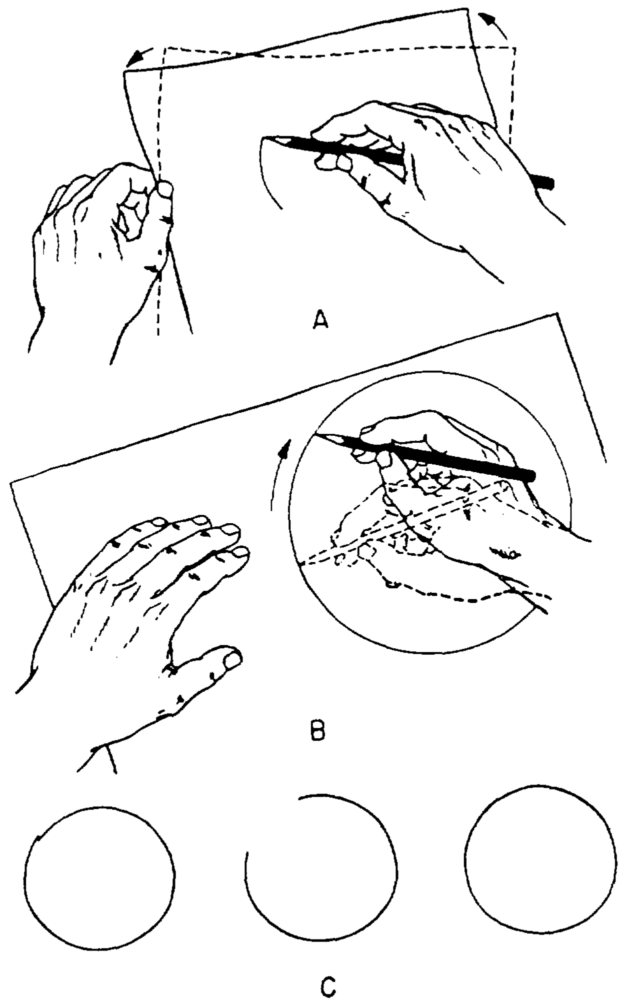
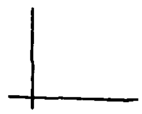


Figure 5-65.-Steps in sketching a circle.

which must be made heavier. Do this as shown in view B. Notice that you DO NOT PIVOT on the second finger during this step. You rest your hand on its side and, keeping it within the circle, trace over the light line with your hand pivoting naturally at the wrist. As you work around the circle in this way, rotate the paper counter-clockwise so that your hand can work in its most natural and easy position. Of course with smaller circles you cannot work with your hand within the circle, but the same general approach can be used with success.

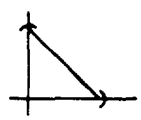
Probably one of the best methods to sketch curves connected to straight lines is the six-step method illustrated and explained below.

1. Intersect a vertical and horizontal line, lightly.

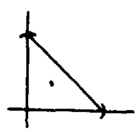


2. Mark off on the horizontal and vertical lines the same distance from the intersection.

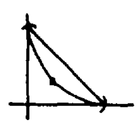
3. Draw a light diagonal line through the two points marked.



4. Place an x or a dot in the exact center of the triangle formed.



5. Start your curve from one point of the triangle preferably on the vertical line) touching the x or dot and ending at the other point of the triangle.



6. Erase all unnecessary guidelines and darken the curve and necessary adjoining straight lines.

A little practice with this method should enable you to improve your ability to sketch curves properly.

Figure 5-66 shows a convenient way to sketch arcs and curves by lightly drawing construction boxes (or blocks).

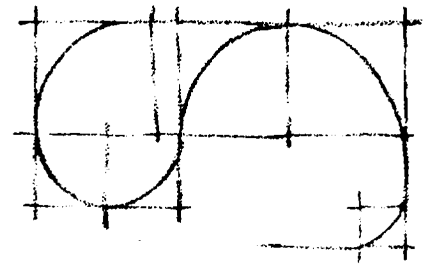


Figure 5-66.-Sketchirrg curves using construction boxes.

Construction Lines

When you are sketching an object, such as that shown in figure 5-67, don't start at one corner and draw it detail by detail and expect it come out with the various elements in correct proportion. It is better to block in the overall size of the object first, (See fig. 5-67, view A.) Then draw light guidelines at the correct angles for the various outlines of the object. (See fig. 5-67, views B and C.)

Finish the sketch by first making an outline of the object and then drawing in the details, as shown in figure 5-67, view D.

Order of Sketching

To make a working sketch, first choose a clean sheet of paper, either plain or ruled. Estimate the size the sketch should be, and select the views that will give the best picture of the object. Then draw the ORTHOGRAPHIC PROJECTIONS of these views, leaving adequate space between them for

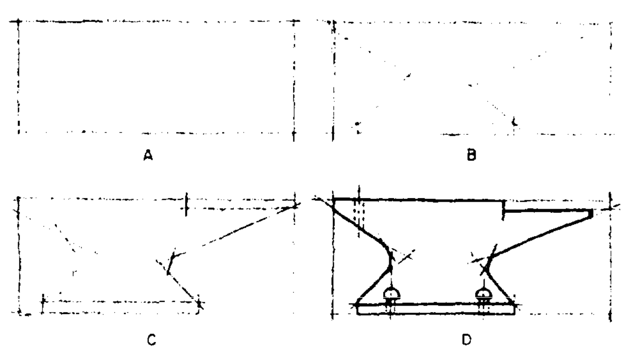


Figure 5-67.-The use of construction lines in sketching an object.

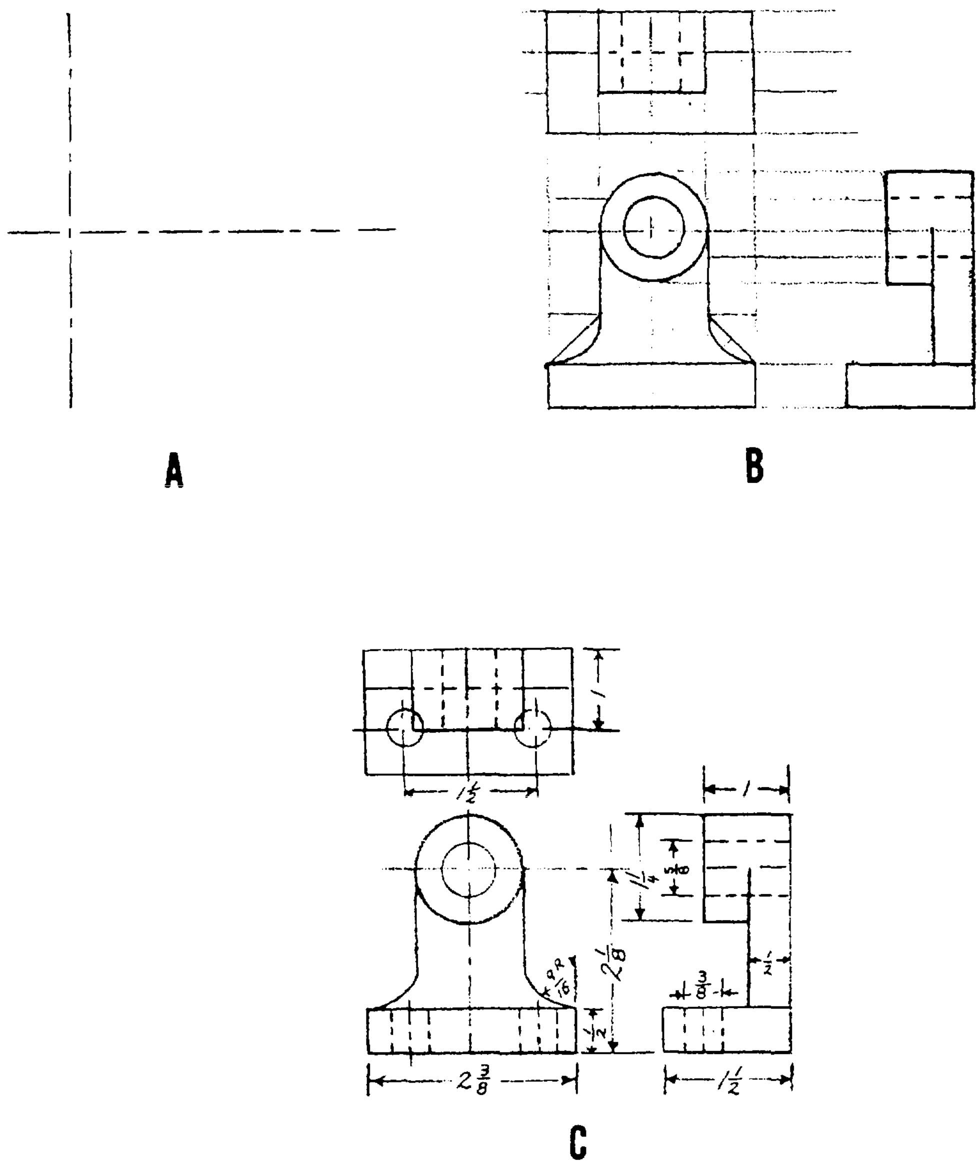


Figure 5-68.-Progress of a working sketch.

dimensions. (Refer to the working sketch in fig. 5-68.) In sketching, progress as follows:

1. Draw the center lines, as shown in figure 5-68, view A.
2. Block in the views.
3. Draw the outlines, aligning them as in figure 5-68, view B.
4. Add the details on the surface of the views.
5. Darken the lines of the finished sketch.
6. Use an art gum or a kneaded eraser to erase the construction lines, which are no longer needed. If necessary, touch up the lines you may have inadvertently erased.
7. Draw all necessary extension and dimension lines.
8. Letter in the dimensions. (See fig. 5-68, view C.)

You can see that a working sketch such as the one shown in figure 5-68 could easily be followed in preparing a finished drawing of the object. The sketch provides you with all the necessary information needed on the finished drawing.

Pictorial Sketches

Often it will be more convenient, or even necessary, to prepare isometric or oblique

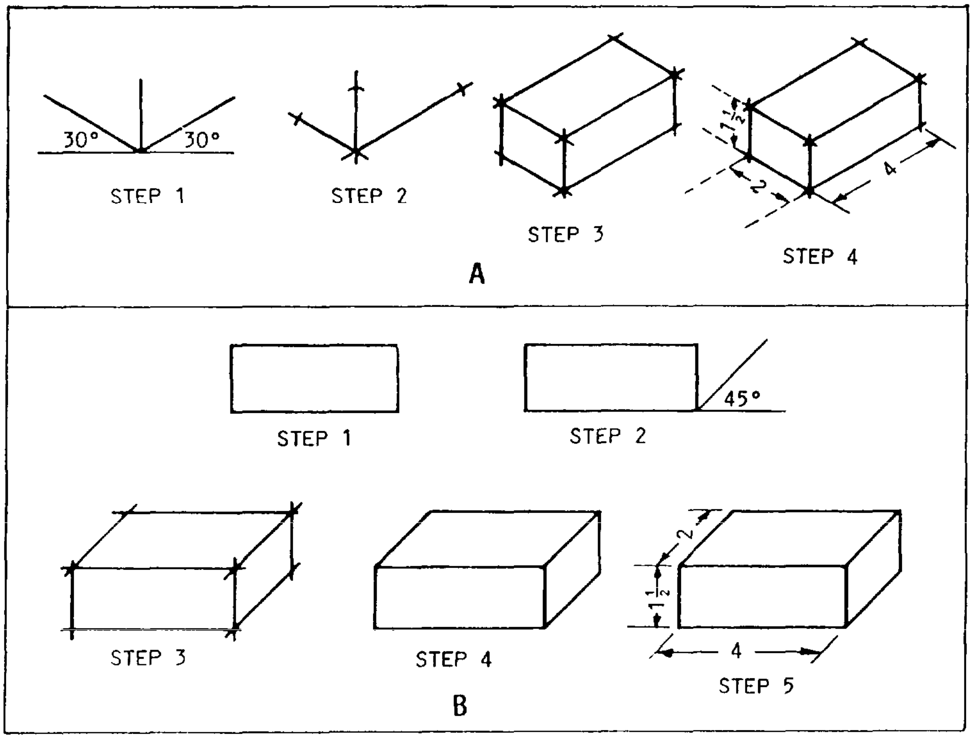


Figure 5-69.-Sketching a rectangular block: A. Isometric; B. Oblique.

PICTORIAL SKETCHES instead of multi-view orthographic sketches. Pictorial sketches provide you with a quick method of examining tentative construction details. A quick pictorial sketch will also help you in the layout of isometric and oblique drawings.

The principles of pictorial and orthographic sketching are similar, except that in pictorial sketching you will be dealing with volumes rather than flat planes. Basically, pictorial sketches and pictorial drawings are practically the same except for the drawing materials used in their development and the fact that pictorial sketches are not normally drawn to scale. By following a few simple steps, based on pictorial drawing construction principles, you should be able to prepare meaningful pictorial sketches.

ISOMETRIC SKETCHES.— Select a position (view) that will show the object to the best advantage. You will know what you want included in your sketch, so move either the object or yourself until you can actually see everything you want to show. If the object is something you have in mind or if you intend to sketch an isometric view from an orthographic drawing, you will have to visualize the object and assume a viewing position. In making your isometric sketch, remember that you start by sketching three isometric axes 120 degrees apart, using two angles of 30 degrees and a vertical axis of 90 degrees. Figure 5-69, view A, shows a step-by-step procedure that can be used in making an isometric sketch of a wooden rectangular block measuring 1 1/2 in. by 2 in. by 4 in.

The first step is to sketch the three isometric axes, as mentioned earlier. The second step is to mark off the 1 1/2 in. for height on the vertical axis, the 2-in. width along the left axis, and the 4-in. length along the right axis. The third step is to draw two vertical lines 1 1/2 in. high (starting with the marks on the right and left axis), then sketch parallel lines from each of the marks on the sketch. Note that the lines that are parallel on the object are parallel on the sketch. The fourth step is to dimension the sketch. The dimensions on an isometric sketch are placed parallel to the ends or edges. The final step is to check the sketch for completeness and accuracy.

OBLIQUE SKETCHES.— The front face or view of an OBLIQUE SKETCH is drawn the same way as an orthographic front view. Using the same wooden block that was sketched

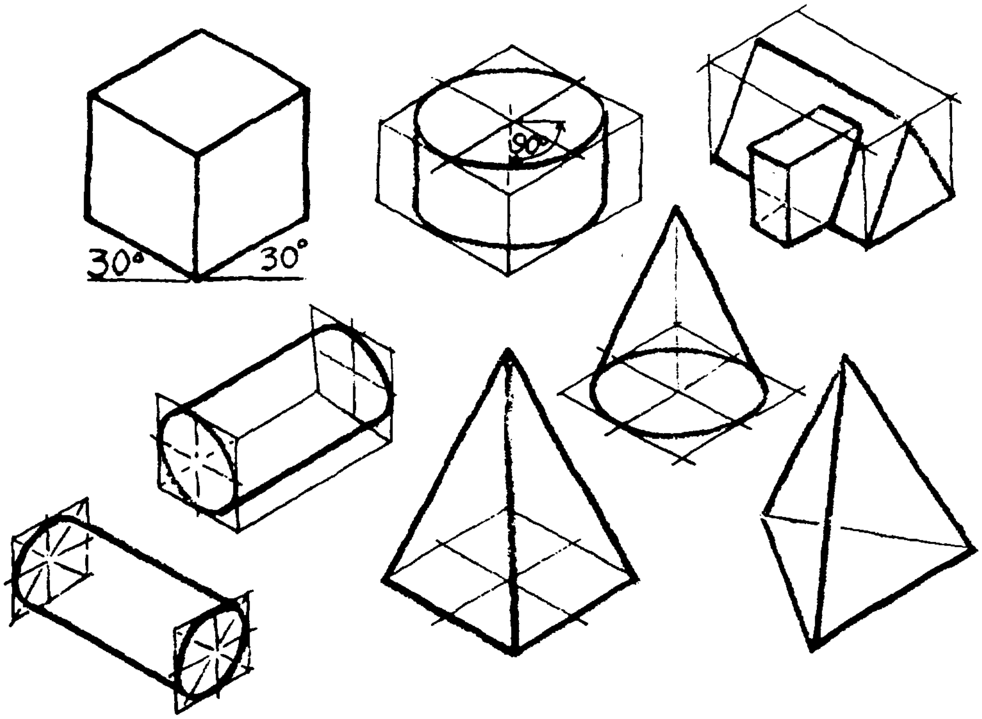


Figure 5-70.-Basic isometric forms.

isometrically for a model, you should draw an oblique sketch following the basic steps shown in figure 5-69, view B.

The first step is to draw a rectangle of the front view (using light lines). Then, second, draw an oblique base line at a 45-degree angle starting at the corner (intersection) of the horizontal and vertical base lines. Third, sketch the remaining horizontal and vertical lines parallel to the other base lines. Fourth, erase any unnecessary lines, and fifth, dimension and darken the completed drawing for easier reading. Remember, place the dimensions so they are parallel to the axis lines. The final step is to check the sketch for completeness and accuracy.

In the above procedures for development of pictorial sketches, a simple rectangular form was used. All objects may be simplified to their basic geometric forms. These forms are the first consideration in the pictorial sketch. Basic volumetric forms are shown in figure 5-70. By carefully analyzing any object you sketch, you will see one or more of the forms shown in figure 5-70. However, at times only a part of a form is present.

Before attempting detailed sketches, practice sketching the basic forms. Then look for these forms in the object you are about to sketch, and concentrate on the basic form representation. Enclose the object in a basic form, or build it up with a series of different forms, depending on the nature of the object. Details are added or "carved" from these forms after shape and proportion have been determined.

Overlay Sketches

To make OVERLAY SKETCHES, sketch freehand on transparent paper placed over existing drawings or other sketches. Sometimes when you make overlay sketches, you merely trace, freehand, objects or lines from another drawing or sketch. But more often you will prepare overlay sketches by tracing and then adding supplementary sketched lines or objects.

Usually, when this type of sketch is prepared, only the prominent or desired features are traced. Overlay sketches are primarily used for planning purposes.

A suggested procedure for using overlay sketches as a tool for planning is explained in the following example:

The drafting room is being relocated. You are tasked with developing a proposed furniture and equipment layout. You have the latest prints of the floor plan and an electrical plan, and you know what furniture and equipment will be moved to the new area. The steps you take to develop the proposed layout are as follows:

1. Check the floor plan and electrical plan against the actual room layout. If necessary, check the dimensions. Correct any discrepancies with a dark-colored fine tip felt pen or colored pencil.

2. Place a piece of tracing paper over the floor plan on the print and secure it with small strips of drafting tape.

3. Trace the outline of the walls with single freehand lines (preferably with a dark-colored felt tip pen). Terminate the lines, where applicable, to indicate windows and door openings.

4. Remove the tracing paper from the floor plan and place it over the electrical plan, lining the traced wall outlines up with the corresponding walls on the electrical plan. Using appropriate symbols, locate, on the traced floor plan, all electrical outlet locations.

5. You now have a clear overlay sketch of the existing floor plan without the unnecessary dimensions and information that are on the original print of the floor plan. This is your basic planning overlay. Check your overlay with the original prints to make sure that relevant lines were not omitted.

6. Place another sheet of tracing paper over the basic planning overlay. This becomes your second overlay. On this second overlay, sketch in your desired location of all the furniture and equipment. Use simple shapes for each and estimate sizes. Use letters or symbols for identification. Repeating the outline of the walls is not necessary because you can still see the outline from the basic planning overlay.

7. If this first location sketch on the second overlay does not suit you or does not provide an adequate layout, lay another piece of tracing paper over the second layout and sketch another layout. Repeat this procedure with additional overlays until you have developed a good layout.

8. Once you have a good layout, trace the wall outlines from the basic planning overlay. This final overlay sketch is your proposed furniture and equipment layout for the new location of the drafting room.